GEOARCHAEOLOGY OF THE BURNTWOOD CREEK ROCKSHELTER
(14RW418), NORTHWEST KANSAS

BY

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Submitted to the graduate degree program in Anthropology and the
Faculty of the Graduate School of the University of Kansas
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Master's of Arts

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ABSTRACT

The Burntwood Creek rockshelter (14RW418) in northwestern Kansas is a large, amphitheater-shaped alcove formed in the Ogallala Formation, a late Miocene/Pliocene-age lithostratigraphic unit underlying the High Plains surface. The processes of rockshelter formation are ascertained through (1) description of the soils and sediments, (2) analysis of the geometry of sedimentary units, (3) grain-size analysis, and (4) thin-section analysis of a carbonate mass. Stable carbon isotope and phytolith data are used to reconstruct late-Quaternary paleoenvironments, and to explore prehistoric Native American subsistence strategies. Results indicate the rockshelter formed by groundwater sapping, and that a complex plant community existed in or around the rockshelter and changed in composition during the late Holocene. Archaeological excavations exposed a 3 m-thick package of late-Quaternary alluvial and colluvial deposits in front of the shelter. These deposits contain stratified Late Plains Archaic and possibly Late Paleoindian cultural materials. Near the back of the shelter, three buried soils are developed in the upper 1.5 m of colluvium.

ACKNOWLEDGEMENTS

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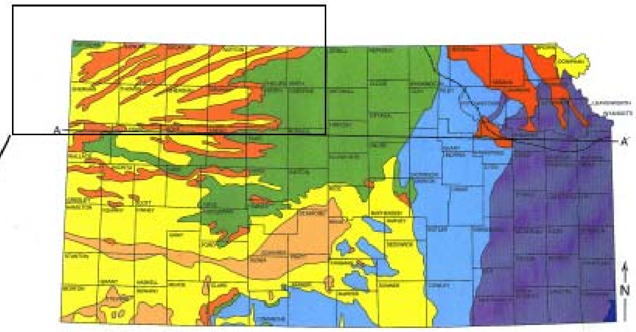
# CHAPTER I

# INTRODUCTION

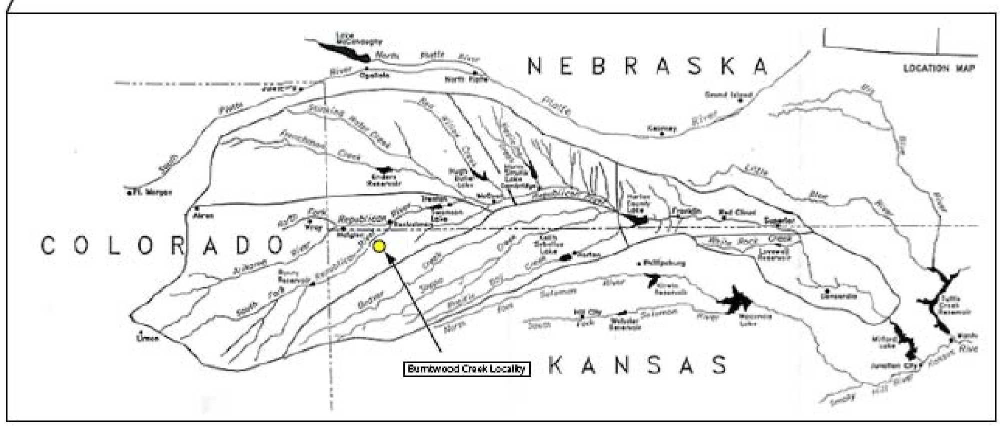
The Burntwood Creek locality contains five registered archaeological sites (14RW2, 14RW3, 14RW4, 14RW5, 14RW418) and is located 16 km north of the town of McDonald, Kansas, in the northwest corner of Rawlins County within the Republican River drainage basin (Figures 1 and 2). The Kansas State Historical Society and the University of Kansas Anthropology Department in conjunction with the Odyssey Archaeological Research Program have conducted systematic and opportunistic pedestrian surveys and limited excavations in recent years at the Burntwood Creek locality.

Most of the recent work has been at site 14RW2, a Late Paleoindian bison jump containing a thick package of *Bison antiquus* bones at the base of a large outcrop of the Ogallala Formation, a late Miocene/Pliocene-age lithostratigraphic unit underlying the High Plains surface. The bonebed dates to approximately 9,000 $^{14}$C yr B.P. based on multiple radiocarbon ages determined on bone collagen, and on organic-rich sediment. Projectile points and lithic material associated with the Allen technological complex (9500-8500 $^{14}$C yr B.P.) have been recorded from the bonebed (Hofman 2002, Jack Hofman, personal communication 2007).

Site 14RW3 is located north of 14RW2 along an outcrop of the Ogallala Formation, and contains many fragments of bison bone. This bone bed appears to represent a separate kill or butchering site of unknown relationship to 14RW2.



Source: Kansas Geological Survey




Source: U.S. Bureau of Reclamation

Figure 1: The Republican River drainage basin in the states of Kansas, Colorado, and Nebraska within the Central High Plains. The inset map is a generalized geologic map of Kansas. The yellow color represents Quaternary loess and river valley deposits and the dark orange represents outcrops of the Miocene/Pliocene Ogallala Formation. These deposits are representative of the Central High Plains subprovince.


Figure 2. Google Earth image of the Burntwood Creek Locality showing the five registered archaeological sites. Green dots represent the locations of permanent datums set between 2006 and 2007.

On the west side of Burntwood Creek and southwest of sites 14RW2 and 14RW3 is site 14RW418, a rockshelter of unknown relationship to the other recorded sites in the valley. The rockshelter is a large, amphitheater-shaped alcove formed in the Ogallala Formation. In western Kansas, the Ogallala Formation consists of carbonate-cemented alluvium, and the "caprock" forms the overhang of the Burntwood shelter (Figure 3). Burntwood Creek, a low-order stream, flows in an entrenched channel in front of the shelter, and a spring emanates from the back of the shelter. Limited archaeological investigations in 2006 revealed stratified Late

Archaic and possibly Late Paleoindian cultural materials. Thus, the potential for the rockshelter to contain new and significant information concerning prehistoric Native Americans and rockshelter formation in the High Plains provided the motivation for this thesis. A detailed geoarchaeological analysis of 14RW418 based on 2007-2008 fieldwork and laboratory work is presented in this thesis.

Figure 3. The Burntwood Creek Rockshelter (14RW418). View is to the north. A spring emanates from the back of the shelter. The overhang of the shelter serves as a pour-off during significant rain-fall events.

## Research Objectives

This thesis examines the processes of rockshelter formation at 14RW418. The task is accomplished through (1) description of the soils and sediments, (2) analysis of the geometry of sedimentary units, (3) grain-size analysis, and (4) thin-section analysis of a carbonate mass. Stable carbon isotope and opal phytolith data are used to reconstruct late-Quaternary paleoenvironments. This research also explores prehistoric Native American subsistence strategies and evidence of an archaeological relationship between the bison bonebed at 14RW2 and the rockshelter.

## Significance of Research

This thesis is significant for three reasons. First, few prehistoric sites have been recorded in rockshelters in Kansas, and stratified Late Archaic sites have rarely been recorded in the High Plains of western Kansas. Detailed description, mapping, and dating of the Late Archaic archaeological deposits in stratigraphic context enhance understanding of rockshelter use and occupation in the Central Plains. Second, stable carbon isotope and phytolith analyses at 14RW418 have yielded information about local climate and vegetation that may have influenced prehistoric Native American subsistence strategies at the Burntwood Creek locality. These multi-proxy data are useful when comparing local and regional paleoenvironmental data, and contribute to understanding local vegetation response to climate. Third, knowledge of site formation processes at the rockshelter is enhanced through description of soils and sediments, geometry of sedimentary units, grain-size analysis, and thin-section analysis of a carbonate mass.

Thesis Outline

The remainder of this thesis is organized as follows. Chapter 2 focuses on the setting of the Burntwood Creek locality, considering physiography, climate, soils, and vegetation. Chapter 3 describes the history of investigations at the project area and in the region, and considers Late Paleoindian and Late Archaic archaeological sites in High Plains. Chapter 3 also describes rockshelter formation and processes, Late Archaic rockshelters, and rockshelters in Kansas. Chapters 4 and 5 focus on field and laboratory methods and results, respectively. Chapter 6 summarizes the implications of this thesis, including the potential for future research.

# CHAPTER II

# SETTING

## Physiography

The Burntwood Creek locality lies within the High Plains subprovince of the Great Plains physiographic province (Fenneman 1931). The boundary of the High Plains is defined by the Ogallala Formation (Frye and Leonard 1952:202) (Figure 4). In Kansas, the High Plains is mantled by Quaternary loess, and where the loess is dissected, exposures of the underlying Ogallala Formation occur (Figure 1) (Mandel 2006:17). This region, often referred to as the "Breaks," is characterized by deeply entrenched intermittent streams.

Burntwood Creek is an intermittent, low-order stream in the Republican River basin. The creek drains the northern portion of Rawlins County along with nearby Timber and Driftwood creeks. Annual discharge of Burntwood Creek during prehistoric times is unknown, but would have likely served as a water source attractive to humans and animals. Abundant natural springs from the Ogallala aquifer would have supplied water to Burntwood Creek as they do today, and were likely capable of supporting humans during droughts (Wedel 1986:79). Moreover, seeps from the Ogallala aquifer carved the Burntwood Creek rockshelter through the process of groundwater sapping, and may have produced other areas for shelter in the High Plains that have yet to be discovered.

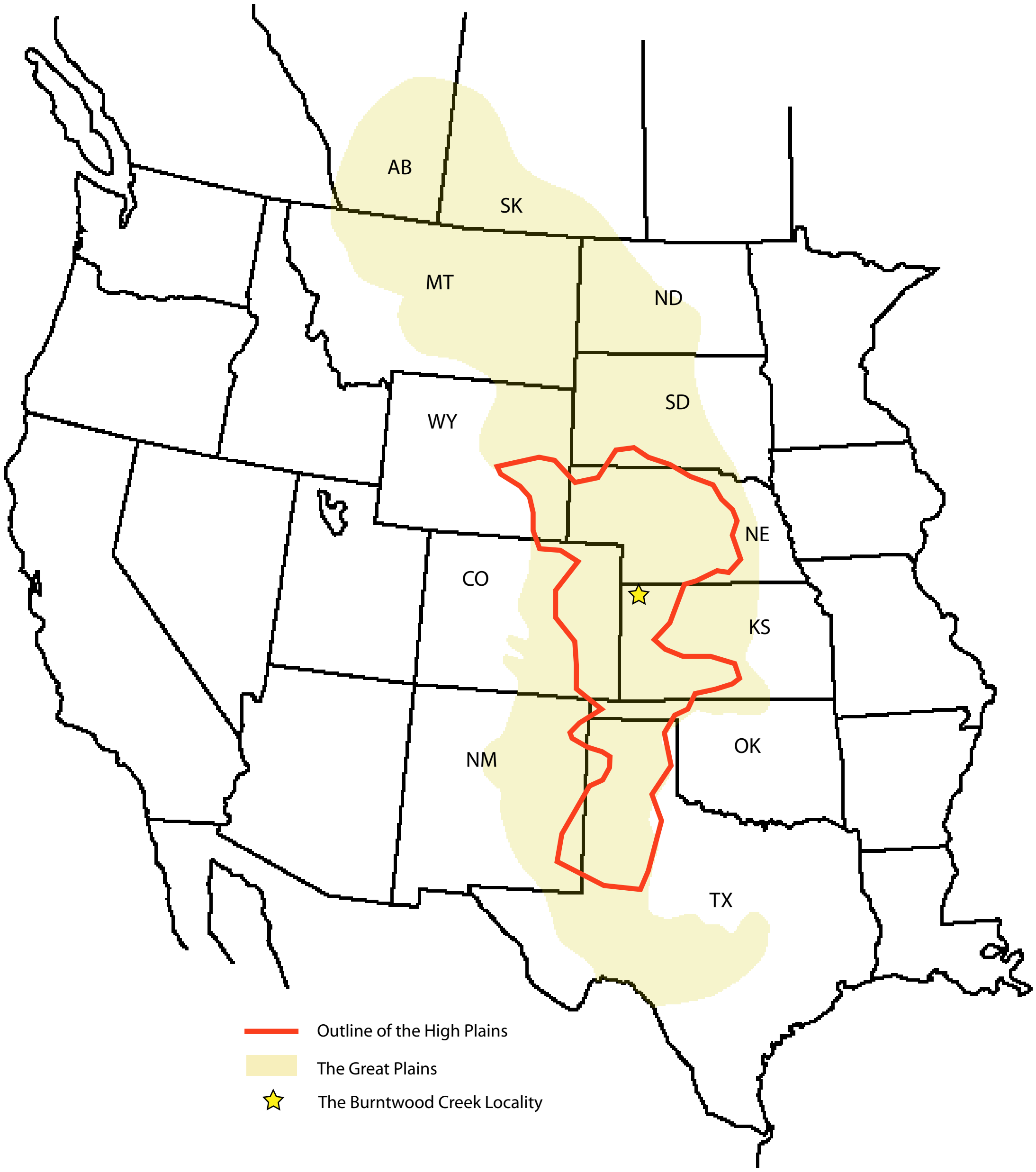



Figure 4. Map of the Western United States with the Great Plains physiographic province highlighted in tan, the High Plains subprovince outlined in orange, and the Burntwood Creek locality designated by a star. The High Plains are defined by the Ogallala Formation (Frye and Leonard 1952:202).

Climate

The climate of the central High Plains is continental; it is characterized by hot summers, cold winters, and low mean annual precipitation (Mandel 2006:18-19). Low mean annual precipitation and warm, dry air are a result of the Rocky Mountain rain shadow (Mandel 2006:19). For Rawlins County, the average summer and winter temperatures are 74.8ºF and 31.3ºF, respectively (USDA 1981:2). Mean annual precipitation along the Kansas-Colorado border is 40 cm (Mandel 2006:19) and is 52 cm in Rawlins County (USDA 1981:54).

The High Plains is also characterized by frequent droughts. Frison (1991:9) notes harsh winters and summer droughts on the High Plains altered local flora, fauna, and Native American subsistence strategies. Wedel (1986:45-48) reports frequent drought cycles using tree ring data from western Nebraska, and infers that severe droughts may have caused abandonment of pre-contact archaeological sites. Wedel (1986) notes that fires and dust storms would have also affected Native Americans.

Soils

According to the NRCS (2007), there are two dominant soils in the Burntwood Creek valley: the Colby silt loam and Bridgeport silt loam. The Colby silt loam is an upland soil developed in loess, and is classified as a mesic Ustic Torriorthent (USDA 1981:71). The Bridgeport silt loam developed in the floodplain of Burntwood Creek, and is classified as a mesic Fluventic Haplustoll (USDA

1981:71). Both soils are well-drained and support short-grass and mixed-grass plant communities (Table 1) (NRCS 2007).

Vegetation

Küchler (1964) prepared a natural vegetation map of the conterminous United States that included the central Great Plains (Figure 5). He also produced a revised vegetation map of Kansas that highlights the transitions in dominant plant communities across the state (Figure 6) (Küchler 1974). Changes in vegetation, or plant communities, are a result of (but not limited to) climate, topography, and quality of soil (Küchler 1969: 164). Generally, the central Great Plains is dominated by tall-grass, mixed-grass, and short-grass prairies. However, isolated patches of riparian forests occur near streams and springs and on rocky outcrops where vegetation is protected from fire (Küchler 1974; Mandel 2006).

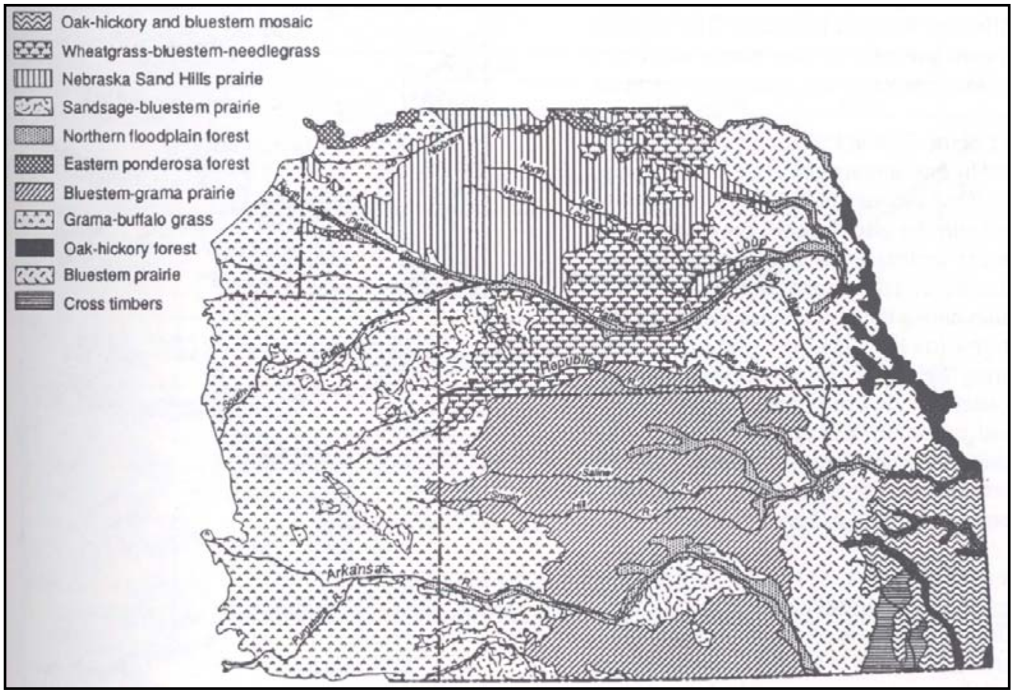


Figure 5. Potential natural vegetation map of the Central Great Plains after Küchler (1964) (from Johnson and Park 1996: 5).

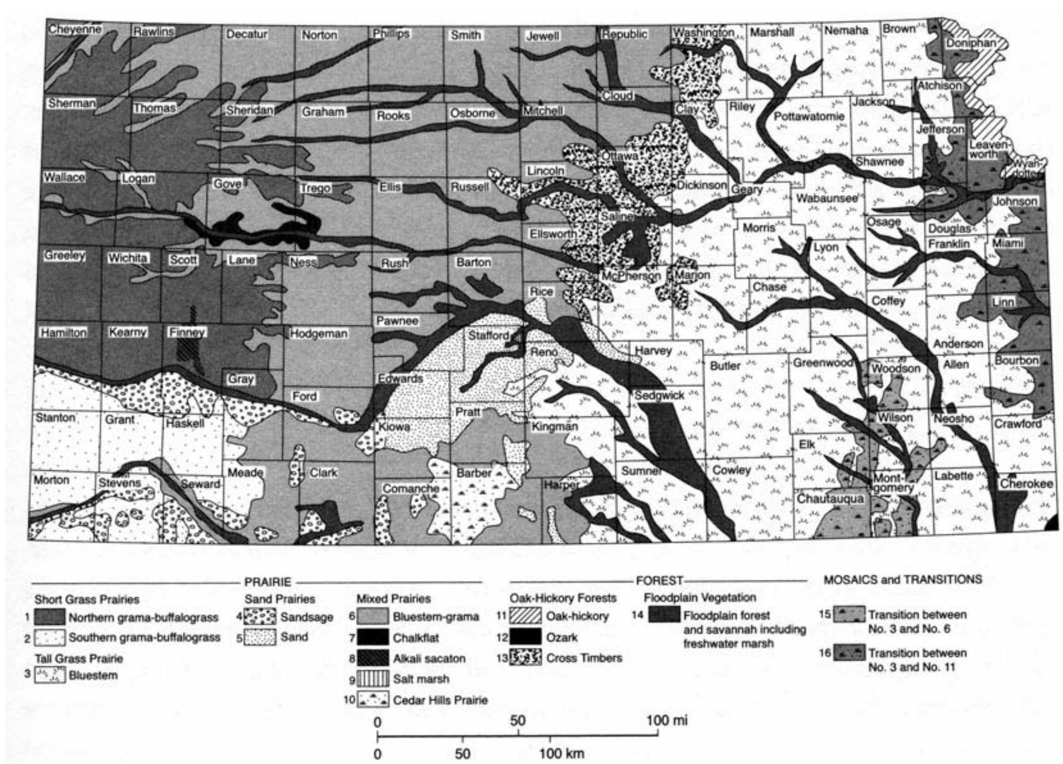


Figure 6. Küchler's (1974) vegetation map of Kansas (from Mandel 2006:21).

Based on Küchler's (1974) map, the natural vegetation of Rawlins County is dominated by a short-grass community of blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloë dactyloides*), and a mixed-grass prairie community consisting of big bluestem (*Andropogon gerardii*) and little bluestem (*Andropogon scoparius*). Wedel (1986:16) added prickly pear (*Oputina*) and yucca (*Yucca glauca*) among the variety of plants within the High Plains (Wedel 1986:21). Riparian forests are dominated by cottonwood (*Populus deltoides*), black willow (*Salix nigra*), and hackberry (*Celtis occidentalis*) (Küchler 1974). The USDA (1981:59) soil survey of Rawlins County lists many of these species and their proportion by soil type (Table 1).

The plant community of the central High Plains is drought-adapted (Table 1). Wedel (1986:16-17) noted that drought resistant short-grasses such as blue grama and buffalo grass have a high nutritional value and provide winter forage for grazing animals. Also, prickly pear was exploited by prehistoric Native Americans during severe droughts (Wedel 1986:16).

Table 1. Characteristic plant communities and their percent composition by soil, Rawlins County, Kansas (adapted from 1981 USDA Soil Survey).

| **Soil Name** | **Characteristic Vegetation** | **% Composition** | **Drought Resistance**[1] |
|---|---|---|---|
| Colby Silt Loam (Upland Soil) | Little Bluestem | 30 | High |
| | Sideoats grama | 15 | Medium |
| | Blue grama | 10 | High |
| | Western wheatgrass | 10 | High |
| | Tall dropseed | 5 | High |
| | Small soapweed | 5 | High |
| | Big Bluestem | 5 | High |
| Bridgeport Silt Loam (Floodplain Soil) | Big bluestem | 30 | High |
| | Western wheatgrass | 15 | High |
| | Switchgrass | 10 | Medium |
| | Little bluestem | 10 | High |
| | Sideoats grama | 10 | Medium |
| | Indiangrass | 5 | Medium |
| | Maximilian sunflower | 5 | Medium |

[1] Source for drought resistance data is the 2008 USDA Online Plants Database.

Lauver et al. (1999) developed an updated natural vegetation classification of Kansas in concordance with national classification standards. Compared to Küchler's (1964) vegetation map, this study provides a higher resolution of plant communities by describing the actual or existing vegetation rather than potential natural vegetation (Lauver et al. 1999:422). Furthermore, Lauver et al. (1999) presented detailed information on habitats, distributions, and expected soils. Sixty plant-community types were defined for Kansas, with twenty-two represented in the High Plains. This system provides a better understanding of the diverse plant communities throughout the High Plains of Kansas and helps refine the species list for a given microhabitat (Lauver et al. 1999:424). Burntwood Creek valley falls within the loess mixed prairie, northern mixed prairie, and short-grass prairie of the herbaceous class, as well as the winterfat-blue grama prairie of the dwarf-shrub herbaceous class.

## Summary

The central High Plains climate is characterized by hot summers, cold winters and low annual rainfall, but contains diverse natural vegetation, including many drought-resistance plant species. The vegetation, as well as streams and springs, would have supported animals, including bison herds, which would have supported Native American groups moving through and residing in the region during the late-Quaternary.

# CHAPTER III

# ARCHAEOLOGICAL CONTEXT

## History of Archaeological Investigations at the Burntwood Creek Locality

The first investigations of the Burntwood Creek locality were at 14RW2, the Late Paleoindian bison jump site (Figure 7). In 1922 and 1923, H.T. Martin, a paleontologist with the University of Kansas, investigated 14RW2 after receiving information from a resident of Atwood, Kansas, who discovered the site 38 years earlier. Based on his observations, Martin (1924) estimated there were over 100 bison in the bonebed. Approximately 2,100 elements collected by Martin are housed at the KU Museum of Natural History, and have been catalogued and studied in recent years. Recent analysis of the bison assemblage includes new estimates of number of animals, age, and seasonality of death (Hill et al. 1992, Hill 2005). Study of this collection continues as part of ongoing research at KU (Russell and Hofman 2006).

The bonebed at 14RW2 was leased as a paleontological and archaeological quarry between 1996 and 2002, resulting in significant damage to the cultural deposits. Professional investigations at 14RW2 began anew in 2004 and have continued each summer through 2007 by the KU Anthropology Department and the Odyssey Archaeological Research Program.

The 2004-2006 archaeological investigations at 14RW2 included beginning the excavation of a vertical trench cut into the bonebed. Additional archaeological units were excavated near the trench, yielding bone and a few chipped-stone flakes. Overall, bone preservation at 14RW2 is good, but bones tend to be highly fractured due in part to natural processes. Many elements were recorded with an EDM total station, cast, and removed. These specimens are now curated at the Archaeological Research Center at KU.

In 2007, a well-preserved right tibia and other elements of a *Bison antiquus* were discovered on the floor of the "south gully," an arroyo near 14RW2 (Figures 7 and 8). A large cultural feature was also discovered in the east wall of the gully directly above the bones (Figure 8). Charcoal and charred organic material were collected immediately beneath the bones and from the feature, and yielded $^{14}C$ AMS ages of 9220 ± 25 yr B.P. and 8880 ± 25 yr B.P., respectively. These ages corroborate the previous 9000 $^{14}C$ yr B.P. ages determined on bone collagen and organic-rich sediment from the bonebed, and fall within the Late Paleoindian period. Also, two Allen points were recovered in recent years at the bonebed, suggesting Late Paleoindians associated with the Allen technological complex were using the bison jump. Other activity areas and possible archaeological complexes at 14RW2 and 14RW3 have yet to be investigated and interpreted.

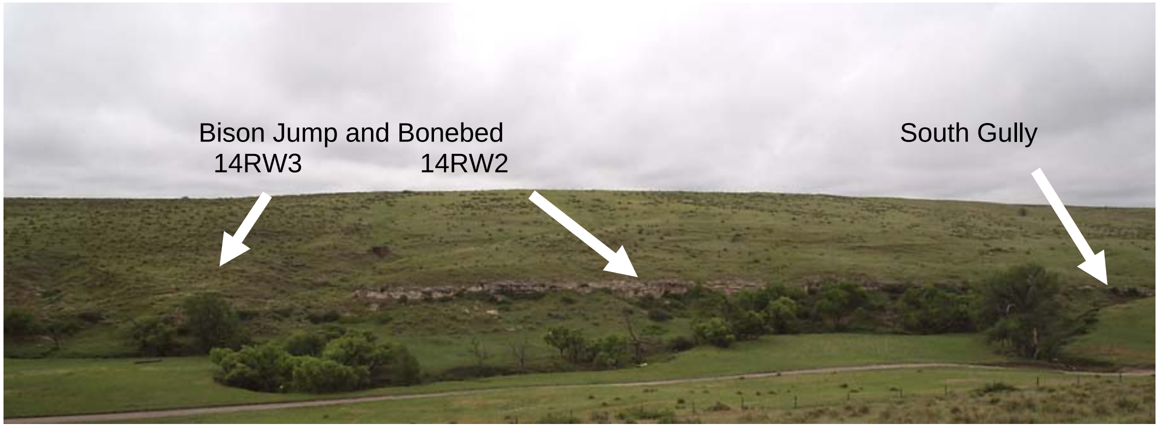



Figure 7. The Burntwood Creek bison jump and bonebed (sites 14RW2 and 14RW3). View is to the east.

**A.** **B.**

Figure 8. A. East wall of the "south gully", or arroyo at the south end of 14RW2. Chris Hord is pointing to the layer of charcoal and ash. B. Top: Floor of the arroyo with *Bison antiquus* elements exposed. View is to the south. Bottom: Close-up view of the right tibia and calcaneous.

The Burntwood Creek rockshelter (14RW418) was recorded by Martin Stein of the Kansas State Historical Society during the 2005 Kansas Archaeological Training Program. Three one $m^2$ test units were excavated in the rockshelter (Figure 9), yielding bone fragments, stone flakes, and charcoal within 50 cm of the land surface. Stein recommended further investigation of the rockshelter to determine depth of the deposits and cultural affiliation.

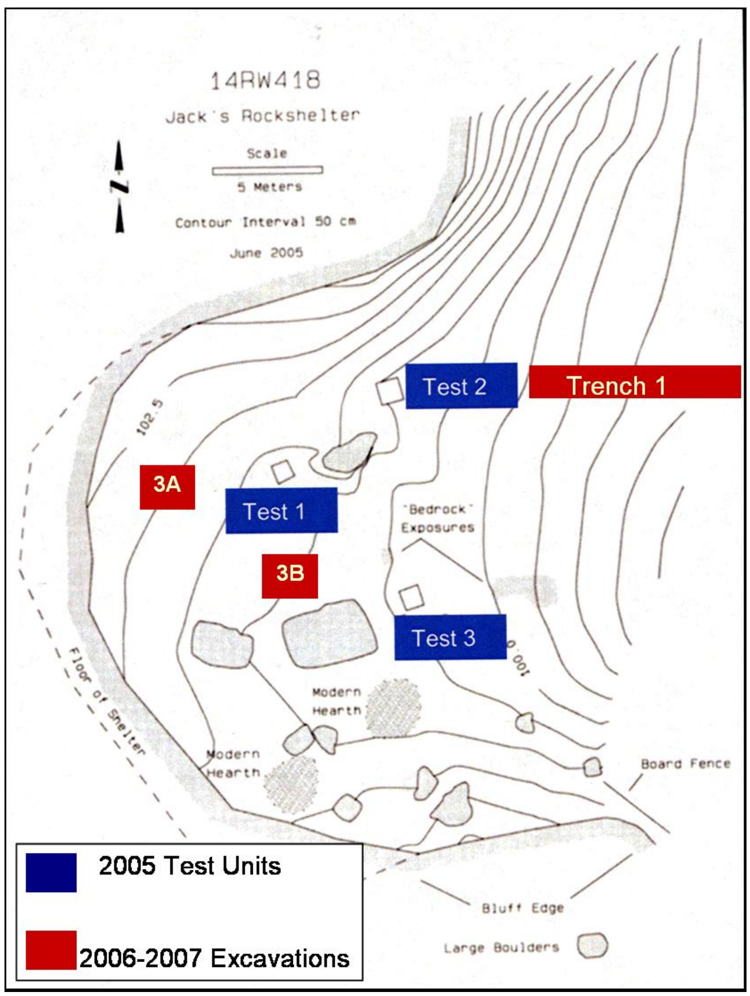



Figure 9. Contour map of the Burntwood Creek Rockshelter (14RW418) showing excavation blocks from 2005-2007.

Deep testing was conducted at 14RW418 during 2006 by the Odyssey Archaeological Research program at KU. A backhoe exposed a 3 m-thick package of late-Quaternary fill in front of the shelter (Trench 1 in Figure 9). Stratified archaeological deposits were exposed in Trench 1, and bone and charcoal samples were collected for $^{14}C$ dating. Collagen from a bison bone 1 m below the surface yielded a $^{14}C$ age of 2220 ± 30 yr B.P. (ISGS A0867). Charcoal was collected in a small trench that was cut perpendicular to Trench 1 at the east end, and yielded a $^{14}C$ age of 1930 ± 30 yr B.P. (ISGS A0859). Also, two bifacial thinning flakes from the lower 50 cm of shelter fill may represent a Late Paleoindian component, based on their technological attributes including parallel oblique dorsal flake scars. Parallel oblique flaking is a characteristic of Late Paleoindian Allen complex technology; hence, the bonebed and lower rockshelter component may be related.

## History of Archaeological Investigations on the High Plains

Prior to the 1920s, archaeological investigations in the Great Plains were limited due to (1) promotion of the Plains as the Great American Desert by scholars such as Henry Lewis Morgan, (2) little exploration prior to westward expansion of settlers and, (3) inadequate funding and personnel for the newly established Kansas and Nebraska State Historical Societies in 1875 and 1883, respectively (Wedel 1986). Active involvement in Plains archaeology increased in the 1920s with the work of E. E. Blackman, A. T. Hill, and W. D. Strong, and by the 1940s, the Works Progress Administration was supporting archaeological surveys and excavations (Wedel 1986).

Extensive Republican River basin surveys and excavations in Kansas and Nebraska were employed between the 1950s and 1970s. The advent of Cultural Resources Management (CRM) in the late 1960s, along with involvement of university-supported archaeologists, has significantly contributed to Central Plains archaeology (Mandel 2000).

Interest in the archaeology of the High Plains increased in the 1930s. E. B. Renaud conducted intensive archaeological surveys in eastern Colorado beginning in 1931 (Wood 1967:3). Also, involvement of the Smithsonian Institution and the National Geographic Society at Paleoindian sites such as Laird and Jones-Miller on the High Plains of Colorado turned attention toward the region.

Archaeological sites within the High Plains are critical for understanding and interpreting the sites found in the Burntwood Creek valley. Late Paleoindian and Late Archaic sites considered relevant to understanding and interpreting the Burntwood Creek locality are described in the following sections.

### *Late Paleoindian*

Lanceolate projectile points with oblique parallel flaking and their variants have defined Late Paleoindian complexes in the Great Pains (Frison 1991, Hofman 1996). Parallel-sided, unstemmed, concave-based projectile points characterized by oblique, parallel flaking of "unusual excellence" were discovered by William Mulloy (1959:112) at a site near Laramie, Wyoming. Mulloy (1959) designated the site James Allen (48AB4) after its discoverer, and it became the type site for the

Allen/Frederick Complex. The Allen/Frederick Complex broadly spans 9400-7800 $^{14}C$ yr B.P., overlapping with Dalton (10,600-9,300 $^{14}C$ yr B.P.) and Cody (9400-8800 $^{14}C$ yr B.P.), two other Late Paleoindian or Paleoarchaic complexes recognized in the Great Plains (Blackmar and Hofman 2006). However, Hofman (2002) refined Allen to 9500-8500 $^{14}C$ yr B.P., and Hill (2005:249) proposed a new age range of 9100-8800 $^{14}C$ yr B.P. based on recently published $^{14}C$ ages (Hofman et al. 1995; Knudson 2002; Mandel and Hofman 2002) from secure stratigraphic contexts (Table 2).

Important and generally well-dated sites associated with the Allen complex include Burntwood Creek (14RW2) (Russell and Hofman 2006), Winger (14ST401) (Mandel and Hofman 2003), and Norton (14SC6) (Hofman et al. 1995) in western Kansas, the Medicine Creek sites (25FT41, 25FT42, and 25FT50) (Roper 2002) and Clary Ranch (25GD106) (Hill 2005) in western Nebraska, Fourth of July Valley (5BL120) (Benedict 2005) in Colorado, and Hell Gap (48GO305) (Irwin-Williams et al. 1973) in southeast Wyoming (Table 2). Although poorly dated, Laird (14SN2) (Hofman and Blackmar 1997, Mandel et al. 2004) in western Kansas is an intriguing bison kill site associated with Dalton technology that has broadened the regional extent of this technology. All of these sites within the High Plains offer glimpses into Paleoindian subsistence strategies and economies.

James Allen, Burntwood Creek, Winger, Norton, and Laird are represented by bison kills with small lithic assemblages, supporting the traditional view of an economy reliant upon bison herds. Fourth of July Valley, the Medicine Creek sites, and Hell Gap are campsites that offer comparison of tool manufacture and activities between the Intermontain and High Plains regions. The Medicine Creek sites and Clary Ranch site have provided the most diverse sets of data spanning the Late Paleoindian period.

The Medicine Creek sites include Lime Creek (25FT41), Red Smoke (25FT42) and Herb Allen (25FT50), where data have been collected and interpreted over the past 70 years. Bamforth (2002:54-55) noted the Medicine Creek sites are significant because of their diverse assemblages and intra- and inter-site variation, and stark contrast to other contemporary Plains sites. While the Allen site seems to be the center of residential activities featuring a 1-m vertical assemblage of hearths within a soil dated to 8700 $^{14}C$ B.P., Lime Creek and Red Smoke represent workshops with over 100,000 pieces of lithic debitage containing representations of Cody, Plainview, Allen, and other technologies. The variety of activity areas and diverse faunal remains recovered from the site alter perceptions of Paleoindians as large game hunters. Similar diverse faunal assemblages were recovered from Claussen (14WB322), a Dalton site in eastern Kansas, further altering perception of Late Paleoindian diets and subsistence (Mandel et al. 2006, Widga 2006).

Table 2. Selected Late Paleoindian sites mentioned in the text.

| State | Site Name | Site Number | Site Type | $^{14}$C Age B.P. | Complex | Reference |
|---|---|---|---|---|---|---|
| Colorado | Fourth of July Valley | 5BL120 | Camp | 8920±50; 9170±40 | Allen | Benedict 2005 |
| Kansas | Norton | 14SC6 | Bison Bonebed | 9080±60 | Cody, Allen | Hofman et al. 1995 |
| Kansas | Winger | 14ST401 | Bison Bonebed | 9080±90 | Allen | Mandel and Hofman 2003 |
| Kansas | Laird | 14SN2 | Bison Bonebed | 8495±40 | Dalton | Hofman and Blackmar 1997; Mandel et al. 2004 |
| Kansas | Burntwood Creek | 14RW2 | Bison Jump/Bonebed | 8880±25; 9220±25 | Allen | This Study |
| Nebraska | Lime Creek (Medicine Creek) | 25FT41 | Workshop | 7980±1000 | Late Paleoindian | May 2002 |
| Nebraska | Red Smoke (Medicine Creek) | 25FT42 | Camp/Workshop | 7970±210-9220±90 | Late Paleoindian | Bamforth 2002; Knudson 2002 |
| Nebraska | Allen (Medicine Creek) | 25FT50 | Camp/Workshop | 8700 | Late Paleoindian | Bamforth 2002 |
| Nebraska | Clary Ranch | 25GD106 | Bison Processing | 9040±35 | Allen | Hill 2005 |
| Wyoming | James Allen | 48AB4 | Bison Bonebed | 7900±400 | Allen (Type Site) | Mulloy 1959 |
| Wyoming | Hell Gap | 48GO305 | Camp | 8600±380 | Allen/Frederick | Haynes et al. 1966; Irwin-Williams et al. 1973 |

Recent investigations at Clary Ranch (25GD106), a bison processing site approximately 200 km northwest of the Medicine Creek sites in Nebraska, have yielded additional information about diet and subsistence practices for Late Paleoindian groups (Hill 2005:249). Based on the large number of bison butchered and processed for meat and marrow during the late summer/early fall, Hill (2005) suggested the Late Paleoindians were storing bison remains for winter. Although this contrasts with the diverse floral and faunal assemblage at the Medicine Creek sites, Hill (2005:261) believes the practices are complementary and demonstrate "settlement and subsistence dynamics on the central Great Plains."

*Late Archaic*

The Plains Archaic period, roughly dated between 8500-2500 $^{14}$C yr B.P. (Kay 1998), is broadly characterized by a locally-focused hunter-gatherer economy. This period began approximately 2,000 years after the Archaic began east of the Mississippi River (Blackmar and Hofman 2006), and was first recognized at the Signal Butte site in western Nebraska in the 1930s (Strong 1935, Frison 1998). However, ages for the Early, Middle, and Late Plains Archaic periods vary significantly in the literature and evolve as new information becomes available (Wood 1967, Wedel 1986, Kay 1998, Tate 1999, Hofman and Blackmar 2006). Furthermore, Late Plains Archaic technology and subsistence strategy often overlaps with the older Middle Plains Archaic and younger Early Plains Woodland. For this study, Late Plains Archaic is considered to roughly span 3000-1800 $^{14}C$ yr B.P., a date range proposed by Tate (1999), whose work focused on the central High Plains.

The Late Archaic has been characterized as a technological continuum from the Middle Archaic, evidenced by an increase in side-notched and corner-notched projectile points (Cassells 1997:123). Several Late Plains Archaic sites in northeastern Colorado within the Platte River Basin, such as Dipper Gap (5LG101), Spring Gulch (5LR252), and Pack Rat Shelter (5LR170), represent multi-component sites that demonstrate technological and economic continuity from the Middle Plains Archaic, and provide evidence for human adaptation in the foothills/hogback and intermontain region of the Rocky Mountains, which includes the use of rockshelters (Table 3) (Wood 1967, Hofman 1996, Cassells 1997, Tate 1999).

The distinction between Late Plains Archaic and Early Plains Woodland sites can be difficult because of significant overlapping in technology and subsistence strategies (Adair 1996). In general, the transition to the Early Woodland is thought to exhibit several characteristics including point type morphology associated with the bow and arrow, and a less mobile lifestyle with the appearance of elaborate burial practices, gardens, ceramics, and eventually agriculture (Adair 1996; Vierra 2005). For the central High Plains, distinction between Late Plains Archaic and Early Woodland is even more difficult due to limited data (Adair 1996:101), and is largely based on point typology (Frison 1998:165). Furthermore, scarcity of recorded Archaic sites in the Central Plains can be attributed to geomorphic processes that have affected the archaeological record (Mandel 1995), and to sampling bias.

Recorded Late Plains Archaic sites are concentrated in eastern Kansas and include Coffey (14PO1) (Schmidts 1978), William Young (14MO304) (Witty 1982), and Snyder (14BU9) (Grosser 1967) (Table 3). These sites contain evidence for multi-faceted economic strategies that included local gathering and exploitation of small game and waterfowl, as well as communal bison hunting (Grosser 1967:135-136).

Many Late Archaic sites in the High Plains demonstrate subsistence strategies that are different compared to the eastern sites, and expand our understanding of large-game hunting practices (Table 3). The Certain site (34BK46) (Buehler 1997) in west-central Oklahoma contains large bison kills and evidence of nut collection and processing (Bement and Buehler 2000). Bison jumps such as Head-Smashed-In and Old Woman's Buffalo Jump in Alberta (Frison 1998:163), as well as arroyo traps such as Kaplan-Hoover (5LR3953) (Todd et al. 2001) in northern Colorado represent a variety of communal bison hunting strategies.

Table 3: Selected Late Plains Archaic sites mentioned in the text.

| State | Site Name | Site Number | Site Type | $^{14}C$ Age B.P. | Cultural Affiliation | Reference |
|---|---|---|---|---|---|---|
| Colorado | Kaplan-Hoover | 5LR3953 | Bison bonebed | 2724±35 | Late Archaic | Todd et al. 2001 |
| Colorado | Wilbur Thomas Shelter | 5WL101 | Camp | ~4500 | McKean Complex | Breternitz 1971 |
| Colorado | Dipper Gap | 5LG101 | Camp/Processing | 3100-3600 | McKean Complex, Late Archaic | Hofman 1996 |
| Colorado | Happy Hollow Rockshelter | 5WL101 | Camp | 2170±80; 2680±90 | Late Archaic | Tate 1999 |
| Colorado | Rattlesnake Shelter | 5WL1856 | Camp | 1920±80-3350±70 | Late Archaic | Tate 1999 |
| Colorado | Spring Gulch | 5LR252 | Camp | 2340±85-2830±135 | Middle Archaic, Late Archaic | Tate 1999 |
| Colorado | Pack Rat Shelter | 5LR252 | Camp | 2440±80-2760±70 | Middle Archaic, Late Archaic | Hofman 1996, Tate 1999 |
| Kansas | Coffey | 14PO1 | Camp | 2480±55; 2320±60 | Walnut Phase | Schmidts 1978; Hofman 1996 |
| Kansas | William Young | 14MO304 | Village/Workshop | 3100±400; 3400±500 | Munkers Creek Phase | Hofman 1996 |
| Kansas | Snyder | 14BU9 | Village Settlement | 2060±80; 1970±110 | Walnut Phase | Grosser 1967; Hofman 1996 |
| Oklahoma | Certain | 34BK46 | Bison jump/Bonebed | 1760±70-1800±60 | Late Archaic | Buehler 1997; Bement and Buehler 2000 |
| Wyoming | Spring Creek Cave | 48WA1 | Camp | 1725 | Late Archaic | Frison 1965, 1998 |
| Alberta, Canada | Head-Smashed-In | Unknown | Bison jump/Bonebed | 3034 to 1924 | Late Archaic | Frison 1998 |

History of Rockshelters

Rockshelters contain well-preserved archaeological materials representing multiple, often repeated or seasonal, occupations. Rockshelters are sediment traps, are protected from erosion and weathering, and they contain deposits that are often sealed under large blocks of roof fall (Goldberg and Mandel 2008). Hence, rockshelters provide important data on prehistoric human ecology (Farrand 2001:29). However, the history of archaeological investigations in North America has been limited compared to Europe, where caves contain deeply stratified deposits dating back millions of years. Examples of North American rockshelters containing long prehistoric human records and good stratigraphic integrity include Rodgers Shelter (23BE125) (Wood and McMillan 1976, McMillan and Klippel 1981) in west-central Missouri, Meadowcroft Shelter in Pennsylvannia (36WF297) (Donahue and Adovasio 1990), and Bonneville Estates Rockshelter (26EK3682) in Nevada (Graf et al. 2002).

*Rockshelter Formation and Processes*

Rockshelters form in a variety of ways. The most common formation process is through differential erosion of stratified sedimentary rocks or lava tubes, and dissolution of limestone through karstic processes (Mandel and Goldberg 2008). Also, groundwater sapping, a process involving outflow from seeps or springs, may erode less-resistant rock, thereby forming a rockshelter. Other processes include stream, wind, and wave erosion (Mandel and Goldberg 2008).

Rockshelters have a shorter life span compared to caves, often lasting less than 25,000 years, and have a greater connection to the outside environment. Evolution of rockshelters is dependent upon bedrock, setting (i.e. topography, climate), size, shape, and intensity of use by both humans and animals (Farrand 2001:30).

Laville et al. (1980:46) recognized that rockshelters are time transgressive. Older sediments are deposited at the front of shelters and are progressively younger toward the back of the shelter with successive collapse of the roof. The breakdown and retreat of the overhang as well as internal and external sediment sources fill and seal rockshelters, often in less than 10,000 years (Collins 1991, Farrand 2001:34). Thus, recognizing Paleoindian-age rockshelters can be problematic.

Rockshelters are very dynamic; geologic processes deliver many sources of sediment that act to both preserve and destroy the archaeological record. Sediment sources include the walls and ceiling of shelters, which deliver clasts through cyroclastism, hydration spalling, and attrition. In addition, alluvial, colluvial, pluvial, and eolian processes often deliver fine-grained sediment, and there may be contributions of anthropogenic (i.e. ash) and biogenic materials (i.e. guano) (Goldberg and Mandel 2008).

*Late Archaic Rockshelters*

Several rockshelters containing well-preserved materials have been investigated in the High Plains region. Rattlesnake Shelter (5WL1856) and Happy

Hollow Rockshelter (5WL101) in northeast Colorado are multi-component sites containing Late Archaic occupations and cultural materials (Tate 1999). The Wilbur Thomas shelter (5WL45) (Breternitz 1971) in northeast Colorado contains stratified prehistoric deposits ranging from the Paleoindian Cody Complex to the Woodland period. At the Wilbur Thomas shelter, the Middle Archaic is represented by two distinct levels associated with the McKean Complex. Spring Creek Cave (48WA1) (Frison 1965) in northern Wyoming contains a Late Archaic assemblage dating to 1725 $^{14}$C yr B.P. (Table 3).

Two rockshelters developed in the Ogallala Formation were recorded in northeastern Colorado by Wood (1967). Both Peary Rockshelter (5LO1) and McEndaffer Rockshelter (5WL31) contain diverse chipped-stone materials, shells, a diverse faunal assemblage, and ceramics. Although these deposits are younger than Late Archaic, they demonstrate adaptive strategies in High Plains rockshelters. Also, Wood (1967) noted that a spring emanated from the back of McEndaffer shelter, and the Ogallala caprock formed the roof of the shelter.

The Kenton Caves in the southern Oklahoma panhandle may contain Late Archaic and Ceramic-age components; however, stratigraphic integrity of the cultural materials was lost due to poor record keeping and haphazard excavation techniques in the 1920s to 1940s (Lintz and Zabawa 1984). Despite preservation of organic materials such as baskets, an atlatl, yucca sandals, and wild and domesticated plants, the ages of the components continue to be “extensively debated” (Lintz and Zabawa 1984:172). Nevertheless, the Kenton Caves document the exploitation of a variety of plants and animals and repeated occupation of caves, likely within the last 2000 years.

### *Rockshelters in Kansas*

Of the 58 recorded rockshelters or caves in Kansas, 34, including the Burntwood Creek shelter, are known to contain prehistoric components; however, only a handful have been thoroughly and professionally investigated (Appendix II). Of the 34 rockshelters with prehistoric archaeological components, 17 are located in southeastern Kansas, with 11 recorded in Montgomery County alone (Figure 10). There is sampling bias due in part to the larger number of archaeological surveys conducted in southeastern Kansas. Appropriate landforms and geology for shelter formation also influences this distribution. Potential shelters in the central High Plains have been noted in recent years during surveys by the Odyssey Archaeological Research Program, but only one has been tested in Rawlins County, and it has likely been subject to significant erosion (Nicholas Kessler 2008, personal communication).

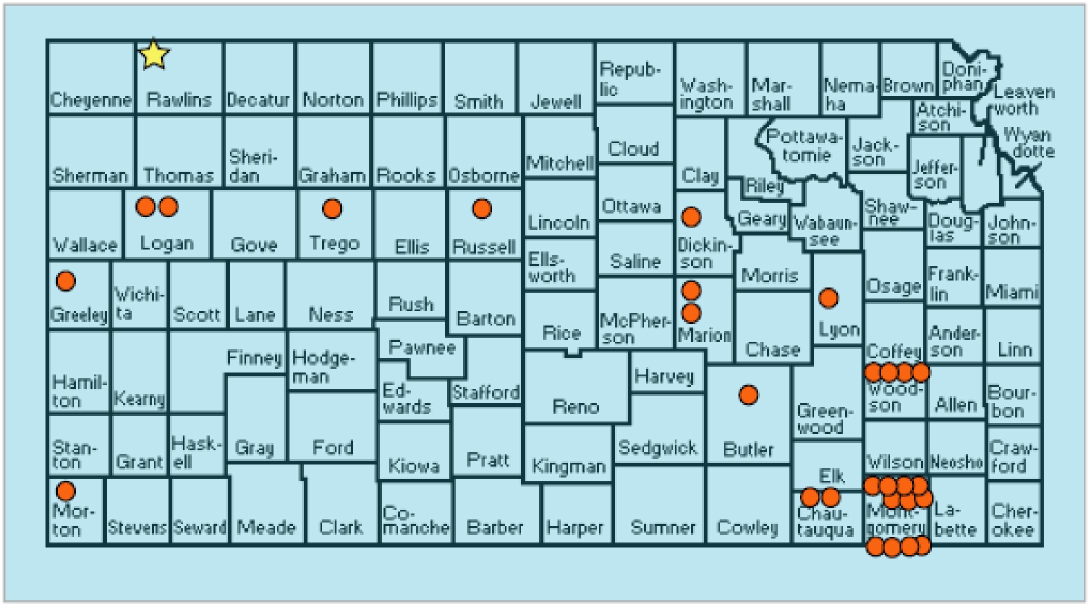



Figure 10. County map of Kansas showing recorded rockshelters or caves containing prehistoric components (orange dots) and the location of the Burntwood Creek rockshelter (yellow star).

## Summary

Paleoindian and Late Archaic local adaptation to environment, including the use of rockshelters is important.  Traditional archaeologically-defined groups and their subsistence strategies are continuously refined and challenged based on new data.  The Burntwood Creek rockshelter offers another piece to the puzzle in discerning adaptive strategies associated with the High Plains environment.

# CHAPTER IV

# METHODOLOGY

The objectives of this research were to perform multi-proxy analyses at the Burntwood Creek rockshelter. Field methodology was driven by what was already known about the rockshelter from previous investigations, and followed well-established protocols for excavation, sampling, and three-dimensional documentation. Laboratory methods were selected on their demonstrated value in the literature for interpreting paleoenvironment, and for assessing rockshelter formation processes.

## Field Methods

Field methods during June 2007 excavations at the Burntwood Creek rockshelter (14RW418) included the re-opening of Trench 1 with a backhoe (Figure 11A), and the opening of two new trenches (3A and 3B, Figure 9) near the back of the shelter. Data gleaned from the trenches were used to assess rockshelter formation and site formation processes, and late-Quaternary paleoenvironments (Murphy and Mandel 2007).

Trench 1 was ~18 m long and 1.5 m wide, but it was widened in some areas to enable removal of 2006 excavation fill. The north wall of Trench 1 was cleaned with a trowel, mapped by hand and by EDM total station, and three profiles were sampled every 10 cm for isotope, phytolith, and grain-size analyses to a maximum depth of 220 cm. Also, a profile was sampled from the west wall of Trench 1 to a depth of 250 cm for grain-size analysis.

Trenches 3A and 3B were excavated with a backhoe until large blocks of roof-fall were reached. These trenches were no more than 2 x 2 m wide. Trench 3A reached a depth of 156 cm and was sampled every 10 cm for isotope, phytolith, and grain-size analyses (Figure 11B). Trench 3B was terminated at a depth of 75 cm and was described but not sampled.

**A.** **B.**

Figure 11. A. 2007 Trench 1. View to the West; B. Trench 3A North wall soil profile.

Sedimentary units were identified on the basis of lithologic characteristics and soils were described following Soil Survey Staff (1996) and Birkeland (1999) terminology (Appendix I). Roman numerals designate the sedimentary units, beginning with Unit I at the bottom of each section. The units are trench specific; therefore, units in Trench 1 and Trench 3A are not the same.

A carbonate mass exposed in the west wall of Trench 1 was sampled at a depth of 1.5-1.7 m below the land surface. Thin-sections were prepared from the sample at Spectrum Petrographics, Inc. and were analyzed using optical cathodoluminescence and epiflorescence microscopy.

Archaeological units from the 2006 field season located immediately adjacent to Trench 1 were re-opened (Figure 12A), and hundreds of lithic flakes were recovered, along with burned deer bone and bison bone fragments, a bison maxilla, and charcoal at a depth of about 1 m below the land surface (Figure 12B). The locations of artifacts were recorded using an EDM total station.

**A.** **B.**

Figure 12. A. Archaeological units immediately adjacent to Trench 1. B. A bison maxilla and two chipped stone artifacts exposed about 1 m below surface.

Charcoal samples collected from cultural features in Trench 1 were sent to the University of California-Irvine Isotope Laboratory for AMS radiocarbon dating. In addition, three bulk soil samples from Trench 3A were sent to the Illinois State Geological Survey for conventional radiocarbon dating of soil organic matter (SOM).

## Laboratory Methods

### *Stable Carbon Isotope Background*

The $^{13}C/^{12}C$ stable carbon isotope ratios in soil organic carbon reflect the photosynthetic pathways of past $C_3$ and $C_4$ plant communities, critical for interpreting paleoenvironments (Boutton 1996). $C_3$ and $C_4$ plants discriminate $^{13}CO_2$ during photosynthesis differently. $C_3$ plants discriminate $^{13}C$, the heavier isotope, while $C_4$ plants discriminate $^{12}C$, the lighter isotope. The $C_3$ photosynthetic pathway occurs in all trees, most shrubs, and some grasses, while the $C_4$ photosynthetic pathway occurs in most warm season grasses (Boutton 1996). The $\delta^{13}C$ values, or the difference between the $^{13}C/^{12}C$ ratio and a known standard, are expressed in parts per thousand (‰). The $C_3$ $\delta^{13}C$ values range from -32‰ to -22‰ and $C_4$ values range from -17‰ to -9‰, and vary due to the $^{13}CO_2$ discrimination (Boutton 1996). Values between -22‰ and -17‰ represent a mixed plant community of both $C_3$ and $C_4$ grasses.

### *Stable Carbon Isotope Procedure*

Seventy-five samples from four profiles were pre-treated for stable carbon isotope analysis at the Kansas Geological Survey using a modified technique by Haj

(2007). All samples were dried at 50ºC, and homogenized with a ceramic mortar and pestle. Following these pretreatment procedures, 20 mL of 0.5 N hydrochloric acid solution were added to 1 g of soil to remove calcium carbonate. This was repeated until reaction was complete, and then rinsed three times with 40 mL distilled water to remove chlorine. Decalcified samples were dried at 50ºC, pulverized using a synthetic ruby mortal and pestle, and transferred to vials.

Stable carbon isotope samples were analyzed at the Keck Paleoenvironmental & Environmental Stable Isotope Laboratory, University of Kansas, where raw $\delta^{13}C$ values are obtained via high-temperature combustion with a Costech ECS4010 elemental combustion system in conjunction with a ThermoFinnigan MAT253 isotope ratio mass spectrometer. International standards used to calibrate $\delta^{13}C$ values include NIST USGS-24 (graphite) #8541, IAEA-600 (caffeine) and NIST ANU (sucrose) #8542. A pre-calibrated internal standard (DORM-2 dogfish muscle; National Research Council of Canada) is used in the $\delta^{13}C$ calibration curve, as well as for sample %C determination. The precision of reported $\delta^{13}C$ values are based on a linear correction of observed values versus expected values of the standards. Typical standard calibration curves yield an $R^2$ of 0.9994 or greater (Greg Cane 2007, personal communication).

### *Phytolith Analysis Background*

Phytoliths, or “plant stones,” are rigid, microscopic silica bodies deposited in cell walls, cell interiors, and intracellular spaces (Piperno 2006). Phytolith analysis is useful for paleoenvironmental reconstruction in the Great Plains because of the abundance of grasses, morphological differences between $C_3$ and $C_4$ grass subfamilies (i.e. Chloridoideae, Panicoideae, and Pooideae) and their resistance to decay (Piperno 2006). Plant communities respond to climatic shifts. Hence, changes in phytolith assemblages throughout a soil profile may suggest shifts in local environment from warm/dry to cool/moist.

Differentiation between the major grass subfamilies allows better assessment of the proportion of $C_3$ and $C_4$ grasses and how the proportion changes over time. Also, warm/humid and warm/dry $C_4$ grasses can be differentiated, allowing for more precise paleoenvironmental reconstructions compared to stable carbon isotopes. However, $C_3$ trees and shrubs (i.e. Dicotyledonae class) are under-represented in the phytolith record, but are accounted for in stable carbon isotope data. Under-representation of $C_3$ trees and shrubs is due to differential production and preservation (Piperno 2006).

### *Phytolith Analysis Procedure*

Sixteen soil and sediment samples from Trenches 1 and 3A were processed for phytoliths using a modified technique outlined by Bozarth (2006) (Appendix IV). One hundred mL of sodium pyrophosphate were added to each sample to disperse clays. Samples were centrifuged and decanted repeatedly until all clay was removed. After oxidation with hydrogen peroxide, two lycopodium spore tablets, each containing 18,585 spores, were added to each sample to calculate phytolith concentration. Phytolith isolation and slide mounting follow methods used for digesting plant materials outlined in Piperno (2006).

Phytolith samples were mounted on slides using immersion oil, and then analyzed with a standard petrographic microscope. Grass phytoliths were tallied first by family, then genus, and where applicable, species using terminology of Brown (1984). Plant species nomenclature follows the Great Plains Flora Association (1986) and incorporates recent genus name changes noted by Lauver et al. (1999). Changed genera of note include *Schizachyrium scoparium* (little bluestem), formerly *Andropogon scoparius*, and *Pascopyrum smithii* (western wheatgrass), formerly *Agropyron smithii* (Lauver et al. 1999:425). Dicots, elongate cells, charcoal, and unidentified or broken phytoliths were also tallied following suggestions of Twiss et al. (1969), Brown (1984), and Bozarth (2007 personal communication). Phytolith concentrations (phytoliths per gram of sediment) were calculated with the following formula: (# observed phytoliths x # lycopodium spores introduced/ #observed lycopodium spores)/original sample weight.

### *Grain-Size Analysis Background*

Geologists and sedimentologists analyze grain-size in order to discern natural processes such as erosion, transport, and deposition of sediment (Syvitski 1991). These geologic processes are useful to geoarchaeologists seeking to understand both rockshelter formation and archaeological site formation processes. Grain-size data are most often used at rockshelters to reconstruct site formation and to infer late-

Quaternary paleoenvironments (Donahue and Adovasio 1990, Abbott 1997, Farrand 2001, Farrand 2001b).

*Grain-Size Analysis Procedures*

Grain-size analysis was performed on fine-grained sediment samples from the rockshelter using a Beckman Coulter Counter LS200 laser grain-size analyzer. This method is appropriate for grains less than 200 microns and produces high-resolution data for clay and silt fractions. Fine-grained samples were pre-treated with 50 mL of 10% hydrochloric acid solution to remove calcium carbonate and 30% hydrogen peroxide solution to remove organic particles.

All other samples containing a significant amount of grains larger than 200 microns were analyzed with a Rotap using numbers 14, 25, 45, 60, 170, 230 sieves to understand changes in clast-size of the sand fraction, with less-emphasis on changes in silt and clay. Using this method, grain-size data were produced for each sedimentary unit or horizon in Profiles 1 and 4 from Trench 1, and the profile at Trench 3A.

*Thin-Section Analysis Background*

The optical cathodoluminesence (CL) technique bombards a thin-section with high-energy electrons via cathode gun. Excited electrons reflect characteristic visible luminescence traceable to mineral and ion content, specifically $Mn^{2+}$ and $Fe^{2+}$, the principal ions that affect CL emissions in carbonates (Boggs and Krinsley 2006:113).

One practical use of CL microscopy is the ability to analyze digenesis of carbonate sedimentary rocks, such that reducing phreatic environments will produce a bright orange CL image from manganese once stable in solution (Boggs and Krinsley 2006:126). CL is also a tool for screening carbonates for paleohydrologic processes, and is a requirement for performing diagenetic and paleohydrologic investigations using stable isotopes in carbonates (Greg Ludvigson 2007, personal communication).

Epifluorescence microscopy (EF) also stimulates electrons using high-intensity light; emitted light is reflected with a diachronic mirror and returns through the microscope objective at a longer wavelength. Organic acids that assimilate in the carbonate matrix are brightly reflected, and organic acids that have been subjected to digenesis will reflect with less-intensity (Rainey and Jones 2007:900). The EF method is useful for determining primary depositional fabrics of carbonates that have been subjected to overprinting such as aggrading recrystallization, and has been successfully used to determine the development of carbonate deposits (Rainey and Jones 2007).

*Thin-Section Analysis Procedure*

The west wall of Trench 1 revealed a carbonate layer or deposit hypothesized to be either (1) a tufa formed in a freshwater spring, in which case, numerous microphytic and macrophytic fossils should be present, or (2) as a result of reducing phreatic conditions in groundwater. Two prepared thin-sections from the top and bottom of the carbonate mass were polished, scanned under transmitted light, and analyzed with a petrographic microscope to develop an understanding of the minerals, fossils, features, and heterogeneities. Both optical cathodoluminescence and epiflorescence microscopy methods were used to determine the process in which the carbonate mass formed, to assess post-depositional sediment overprinting, and to decide if the deposit was appropriate for uranium series dating.

# CHAPTER V

# RESULTS

This chapter presents the results of analyses from Trench 1, Profiles 1-4, and Trenches 3A and 3B at the Burntwood Creek rockshelter. All soil and sediment descriptions are listed in Appendix I, and raw phytolith counts and calculated percentages are listed in Appendix III. Overall, rockshelter formation processes were gleaned from descriptions of soils and sediments, as well as grain-size and thin-section analyses. Also, major differences were observed between stable carbon isotope and phytolith analyses, shedding light on the paleoenvironmental conditions during the late-Quaternary.

## Trench 1 Results

In Trench 1, seven major sedimentary units, numbered I through VII from the bottom of the exposure to the top, were identified (Figure 13). A 2 m-thick section of Unit I was exposed at the west end of the trench. Unit I consists of stratified sands and two upward-fining sequences. Also, a recrystallized calcium carbonate layer formed in Unit I at a depth of 1.5-1.7 m below the land surface. In the north wall of the trench, the beds of sand comprising Unit I dip to the east at an approximately 35º angle relative to the land surface. Also, the surface of Unit I dives to the east. Based on the geometry, Unit I is likely a package of alluvium derived from spring flow coming out of the back of the rockshelter. However, Unit I may have also been derived from bursts of streamflow associated with the pour-off on the roof of the shelter.

Unit II is brown to dark brown (7.5YR 5/4-7.5YR 4/3) fine loamy sand with few fine reddish brown (5YR 4/4) mottles. The unit is massive and friable, and consists of strongly weathered clasts of Ogallala material. Bodies of brown to dark brown (7.5YR 5/4-7.5YR 4/3) sand were observed in the Ogallala Formation comprising the wall of the rockshelter. Thus, it is likely that Unit II is colluvium derived from the Ogallala.

Unit III is light olive brown to olive brown (2.5Y 5/3-2.5Y 4/3) cobbly silt. It is massive and firm, and contains many angular cobbles and boulders derived from the Ogallala. Unit III slopes to the east and is mantled by fine-grained alluvium comprising Unit IV. Geometry and texture suggest Unit III was delivered to the front of the rockshelter by colluvial processes.

Unit IV is reddish brown (2.5YR 5/3) well-sorted silt interbedded with few siliceous pebbles and few angular cobbles of Ogallala material. Unit IV mantles Unit III and thickens to the east. During excavation of the adjacent archaeological units, multiple layers of charcoal (Feature 2) were exposed in Unit IV at a depth of 1.0 to 1.3 m below the land surface. These charcoal layers were separated by thin layers of sterile silt. Feature 2 contained lithic material, bison elements, and deer- and bison-sized bone. One additional layer of charcoal was recorded in the north wall at a depth of 1.5 m but did not contain cultural material. At the east end of the trench, Unit IV is horizontally bedded with inclusions of Ogallala material. Sorting and horizontal bedding suggest Unit IV is mostly alluvium from Burntwood Creek.

Unit V is light yellowish brown (2.5Y 6/3) silt with many angular pebbles and cobbles of Ogallala material. A cultural feature (Feature 1) was recorded in the upper 5 cm of this unit. Feature 1 is a hearth containing charcoal, flakes, bones, and hackberry seeds. Unit V dips to the east. The geometry of the unit and poor sorting of the sediment indicate that Unit V was formed by colluival processes.

Unit VI, a light olive brown (2.5Y 5/3) silt, is friable, and has weak fine subangular blocky structure. The Bw horizon of the modern surface soil is developed in Unit IV. The lower 5 cm of Unit VI are laminated, suggesting that this package of sediment is slopewash derived from roof of the shelter.

Unit VII, a dark grayish brown (10YR 4/2) silt, is friable and has weak fine granular structure. This unit contains many pebbles and cobbles of Ogallala material, indicating a colluvial origin for the unit. The A horizon of the modern surface soil is developed in Unit VII.

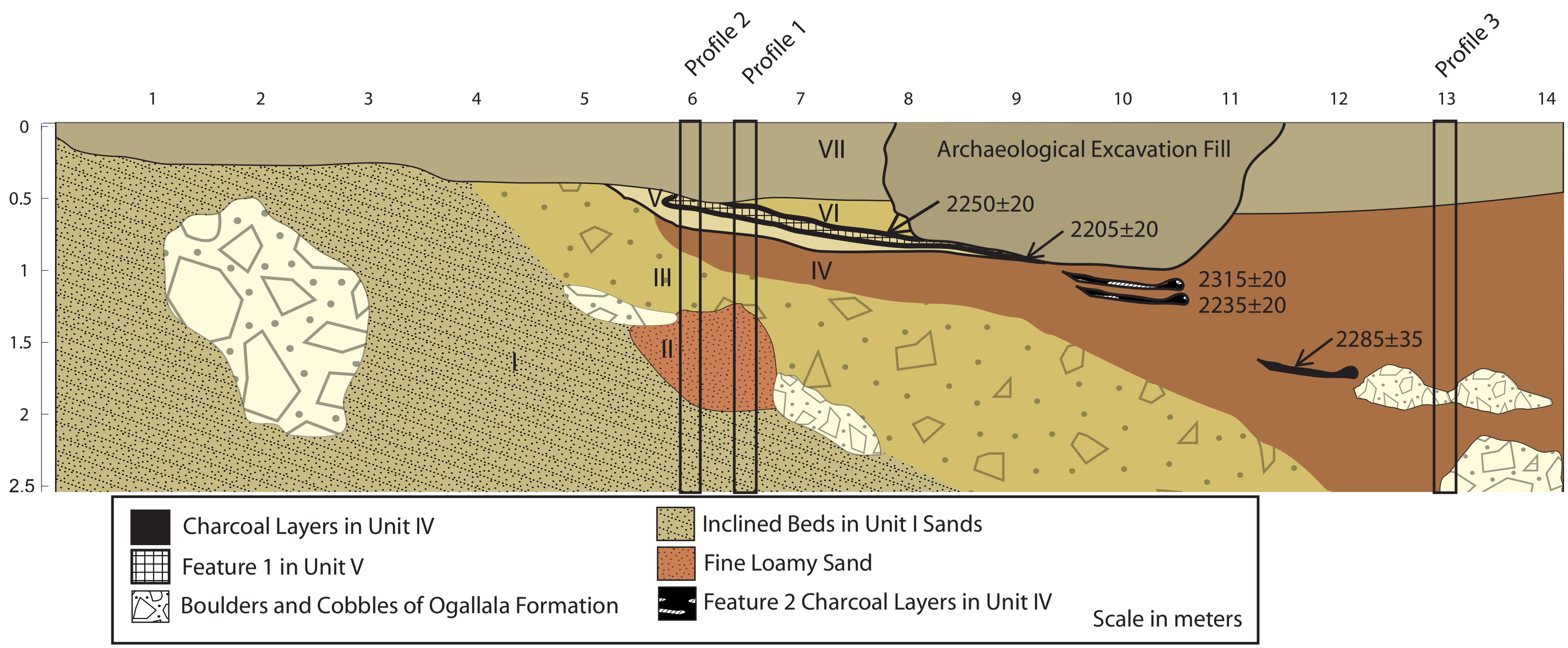



Figure 13. Trench 1. North wall profile drawing showing sedimentary units, profiles, and AMS $^{14}C$ ages described in this study.

Two charcoal samples from Feature 1 in Unit V yielded AMS $^{14}C$ ages of 2250 ± 20 and 2205 ± 20 B.P. (Table 4). In Feature 2 in Unit IV, over 300 flakes, a bison maxilla, and deer- and bison-sized bones were recorded (Figure 14). Two charcoal samples were collected from Feature 2 and yielded AMS $^{14}C$ ages of 2235 ± 20 and 2315 ± 20 B.P. (Figure 13, Table 4). One additional layer of charcoal was exposed in the north wall at a depth of 1.5 m and dated to 2285 ± 35 $^{14}C$ yr B.P. No cultural materials were recorded in this layer (Figure 13, Table 4).

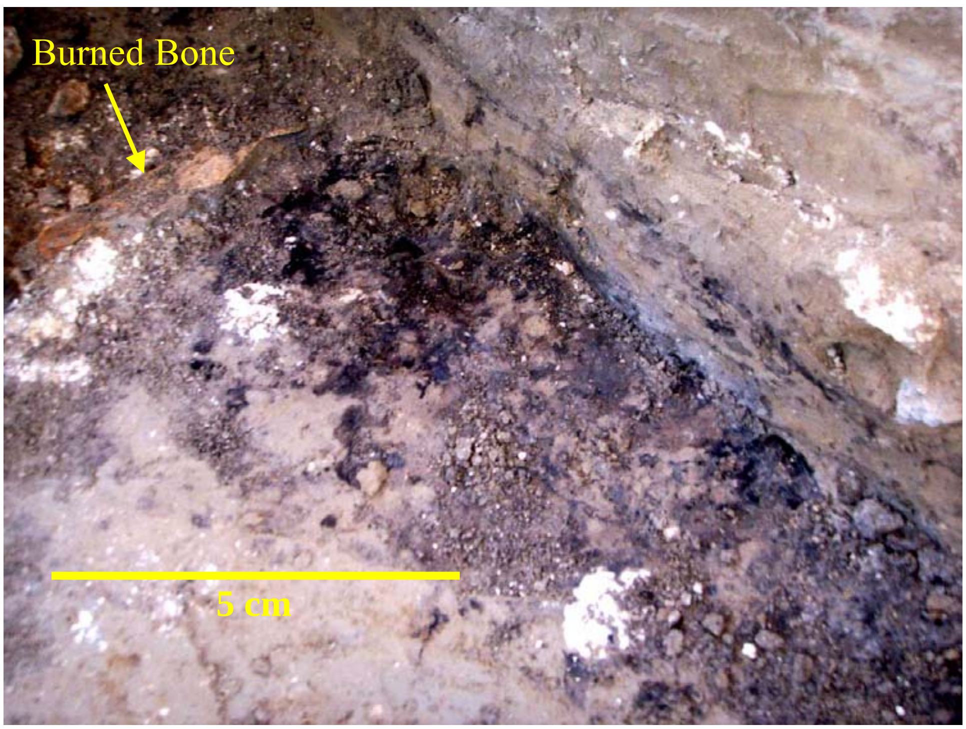



Figure 14. View of Feature 2 in archaeological unit adjacent to Trench 1.

Table 4. Radiocarbon Ages from Trench 1.

| $^{14}C$ yr B.P. | Dating Method | Material | Lab Number |
|---|---|---|---|
| 2220±30 | AMS | Bone | ISGS-A0867 [1] |
| 1930±30 | AMS | Charcoal | ISGS-A0859 [1] |
| 2205±20 | AMS | Charcoal | UCI-41886 [2] |
| 2250±20 | AMS | Charcoal | UCI-41885 [2] |
| 2235±20 | AMS | Charcoal | UCI-41888 [2] |
| 2285±30 | AMS | Charcoal | UCI-41889 [2] |
| 2315±20 | AMS | Charcoal | UCI-41887 [2] |

[1] Samples collected during 2006 excavations and analyzed at the Illinois State Geological Survey.
[2] Samples collected during 2007 excavations and analyzed at the University of California-Irvine Isotope Laboratory for AMS Radiocarbon Dating.

Profiles 1, 2, and 3 were described and sampled from the north wall of Trench 1, and Profile 4 was sampled from the west wall. Profiles 1 and 2 were sampled through all seven units and were 50 cm apart (Figure 13). Profile 3 was sampled through Unit IV alluvium near the east end of the trench. Stable carbon isotope, phytolith, and grain-size results from these three profiles are described in the following sections.

### *Profiles 1 and 2*

Profiles 1 and 2 yielded $\delta^{13}C$ values that are typical of $C_3$ plant communities (Figure 15). The $\delta^{13}C$ values shift 1-2‰ heavier up both profiles, suggesting an increase in the proportion of $C_4$ plants. However, the $\delta^{13}C$ values tend to shift back and forth rapidly, but trend toward lighter $\delta^{13}C$ values in Unit V, the unit containing Feature 1. The organic carbon content (%C) is high in the surface soil, and steadily declines with depth (Figure 15).

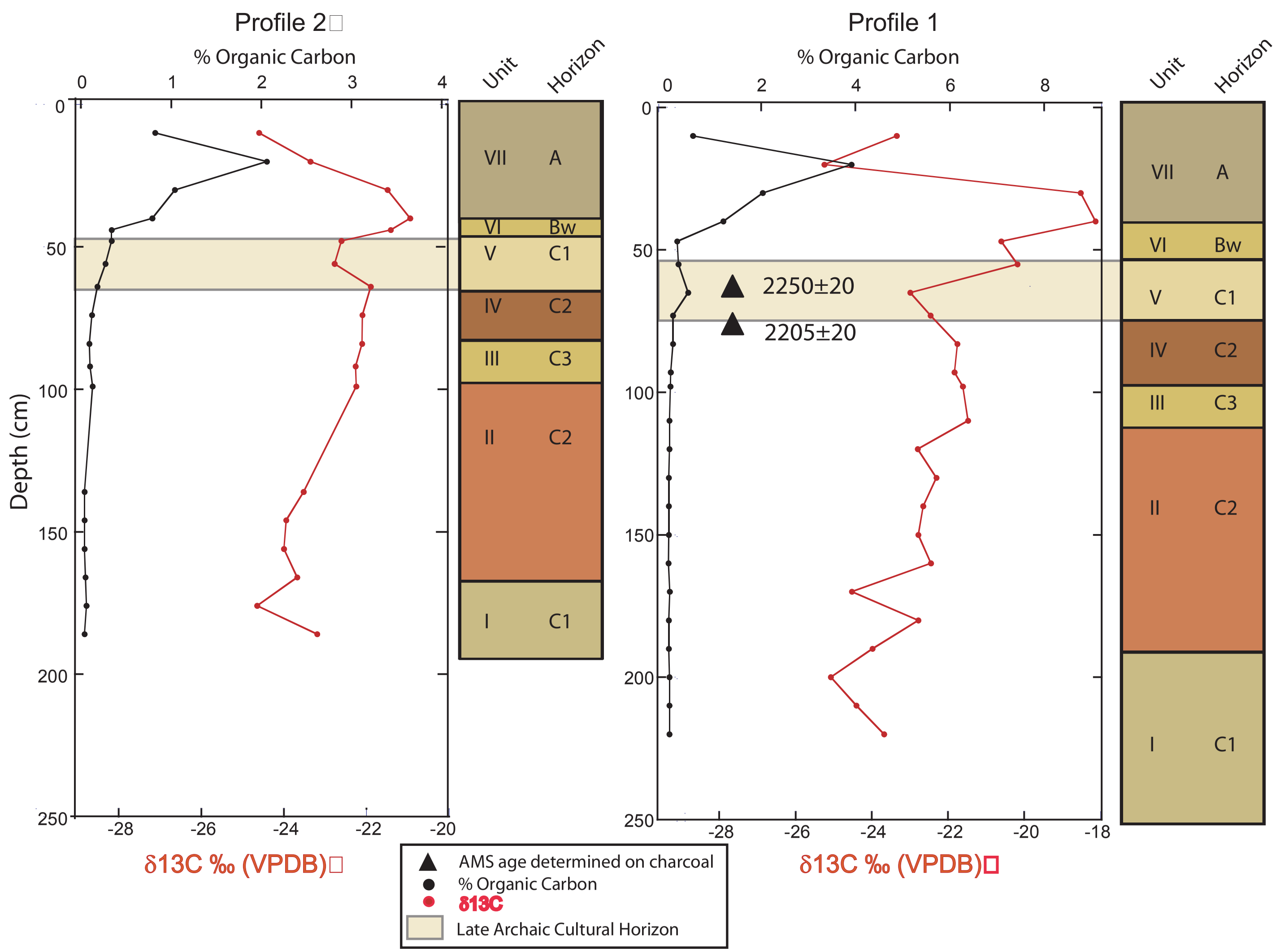



Figure 15. Depth function diagram for Profiles 1 and 2 in Trench 1.

The phytolith data for Profile 1 have three important trends from the bottom of the profile to the top (Figure 16). In Units I and II, there is a dominance of $C_3$ pooids, unlike the rest of the profile. The increase in pooids in the lower meter of the sequence corroborates the lighter $\delta^{13}C$ values. Also, there is a greater number of broken phytoliths and other unidentified short cells in Units I and II, likely due to alluvial transport and redeposition from the back of the shelter or off the top of the shelter. Units III and IV exhibit a large increase in $C_4$ chloridoids up the profile, indicating an increase in aridity that is not as well represented in the $\delta^{13}C$ data. Unit V containing Feature 1 exhibits a dramatic spike in the Dicotyledonae class, attributed to the large number of hackberry fruit and leaf phytoliths (Table 1 in Appendix III).

A concentration of burned hackberry seeds were observed in Feature 1 during excavations. The overwhelming dominance of leaf rather than fruit phytoliths suggests hackberry trees were nearby, depositing leaves on the land surface as they do today. However, given the concentration of hackberry phytoliths and seeds within Feature 1, hackberry branches may have been used by prehistoric Native Americans for burning, and hackberry fruits may have been consumed. The shift toward lighter $\delta^{13}C$ values in Unit V (Figure 15) corroborates the increase in $C_3$ phytoliths.

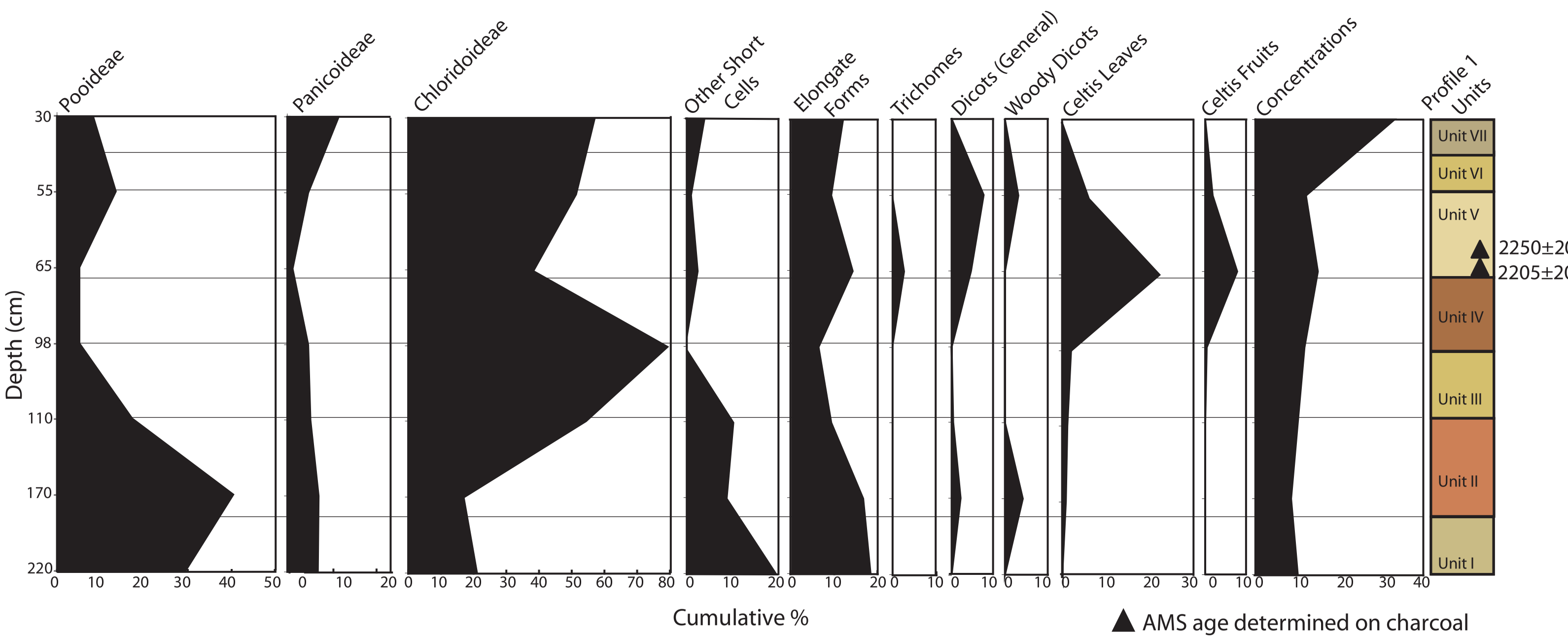



Figure 16. Phytolith diagram for Profile 1 in Trench 1. Woody dicots are spinulose spheres, general dicots include tracheids, and polyhedral and jigsaw puzzle piece cells.

*Profile 3*

In Profile 3, only Unit IV was described and sampled (Table 3 in Appendix I). The $\delta^{13}C$ values from Profile 3 are not conclusive; they exhibit frequent excursions typical of alluvium (Figure 17). However, three trends are apparent. The C2 and C3 horizons exhibit a general trend from heavier $\delta^{13}C$ values to lighter values. At the boundary between the C2 and C1 horizons there is a shift toward heavier $\delta^{13}C$ values before another shift of approximately 2‰ back to lighter values. In general, $\delta^{13}C$ values average approximately -20‰, suggesting $C_3$ plants were in greater proportion to $C_4$ plants throughout the profile. The depth function for C content is normal; C values are high at the top of the profile, indicating pedogenic C input, and steadily decrease down the profile.

Grain-size data for Profile 3 were analyzed with a Coulter Counter, and exhibit four upward-fining sequences (Figure 17). The proportion of fine silt increases towards the top of each sequence and is accompanied by an increase in C content. Slight shifts in %C probably are from detrital carbon at the top of each upward-fining sequence.

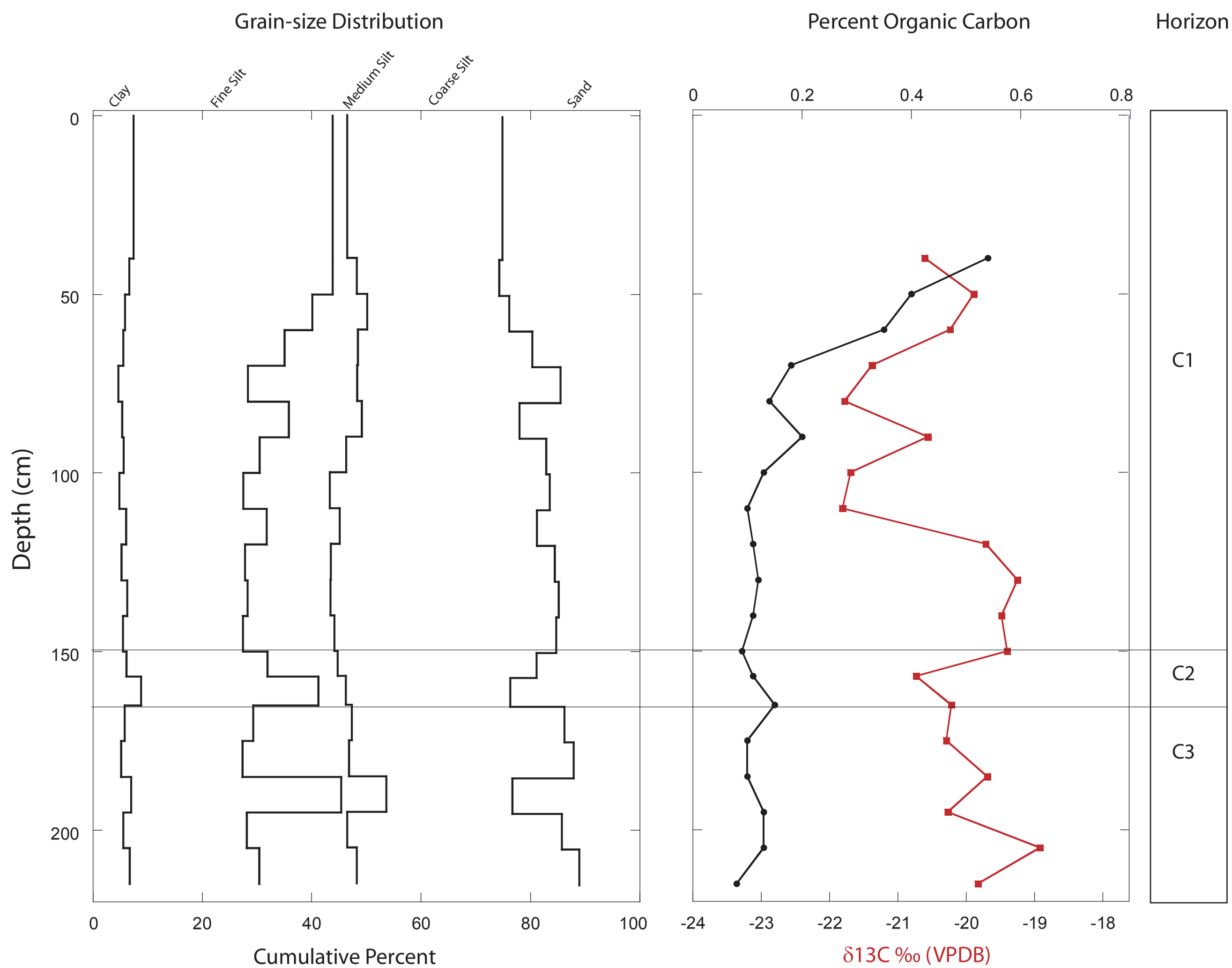



Figure 17. Depth function diagram for Profile 3 in Trench 1.

Profile 3 was fairly homogeneous; therefore, phytoliths were extracted from the bottom and top only (Table 2 in Appendix III). The bottom sample at 185-195 cm produced a mixed assemblage of pooids, chloridoids, and dicots (Figure 18). At 40-50 cm, $C_4$ chloridoids are dominant (Figure 18). Because these phytolith samples are from alluvial sediments, it is likely the phytoliths were transported and redeposited from their original source. This is especially evident at 185-195 cm, where concentrations of phytoliths are low and preservation is poor. The phytolith assemblage from 185-195 cm corroborates $\delta^{13}C$ values, but the assemblage from 40-50 cm does not. It is likely that $C_3$ arboreal and herbaceous plants are under-represented in the alluvial sediment.

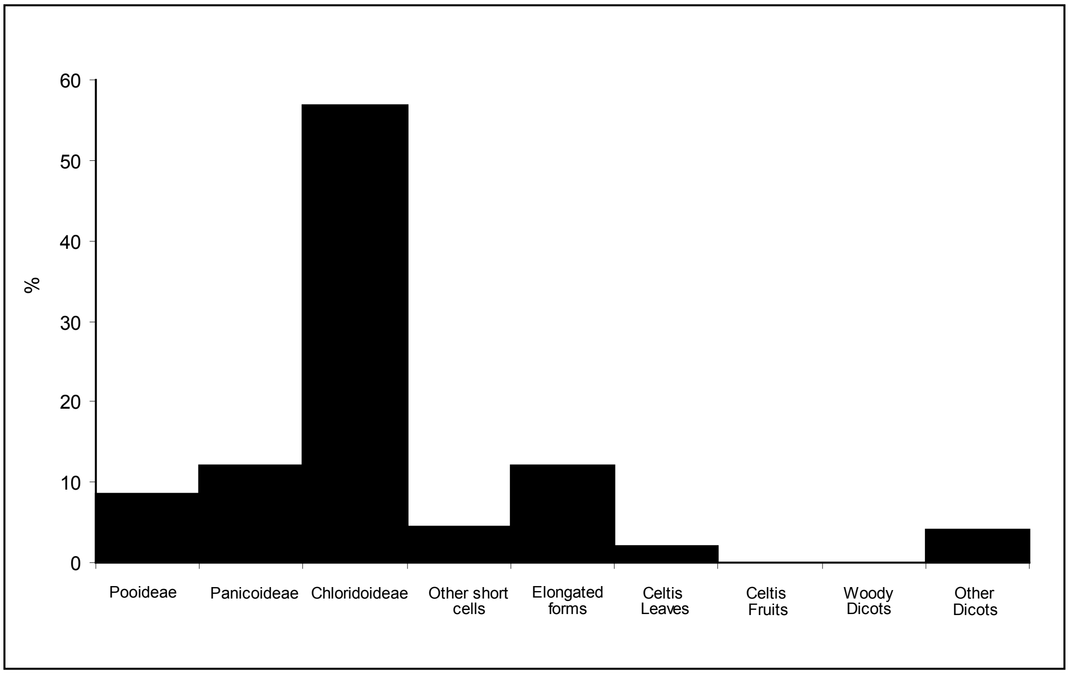



Figure 18. Phytolith diagram for Profile 3 in Trench 1, 185-195 cm.

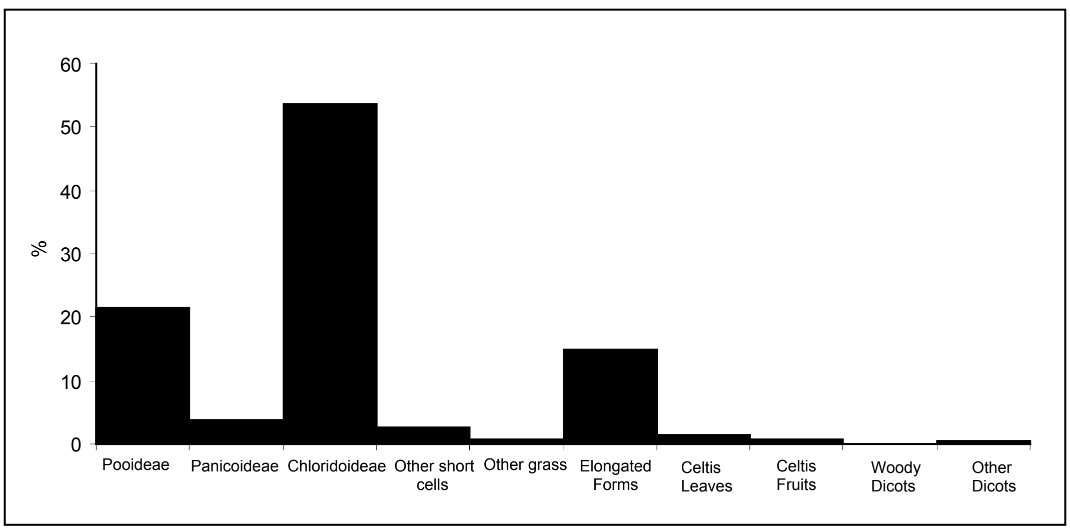



Figure 19. Phytolith diagram for Profile 3 in Trench 1, 40-50 cm.

*Profile 4*

In Profile 4, 14 horizons were identified in a 2 m-thick section of Unit I at the west end of the trench (Table 4 in Appendix I). Stratified sands and two upward-fining sequences are apparent in the grain-size data (Figure 20). There is a modern surface soil developed in Units VI and VII, capping Unit I. A rotap was used to detect changes in the sand fraction through the entire profile.

Unit I is mostly comprised of yellowish brown (10YR 5/4) and light yellowish brown (2.5Y 6/3) medium and coarse sand interbedded with light olive brown (2.5Y 5/4) and light yellowish brown (2.5Y 6/3) fine sand (multiple C horizons). The C horizons are massive, but the sand easily parts to single grain. Parallel bedding occurs in all of the C horizons in Unit I except the C6 horizon, which is cross-bedded. Siliceous pebbles occur in many of the C horizons, and angular clasts derived from the Ogallala Formation exist in all horizons above the Ck3 horizon. Secondary carbonate accumulations occur as common fine threads in the Ck, BCk, and Bk horizons.

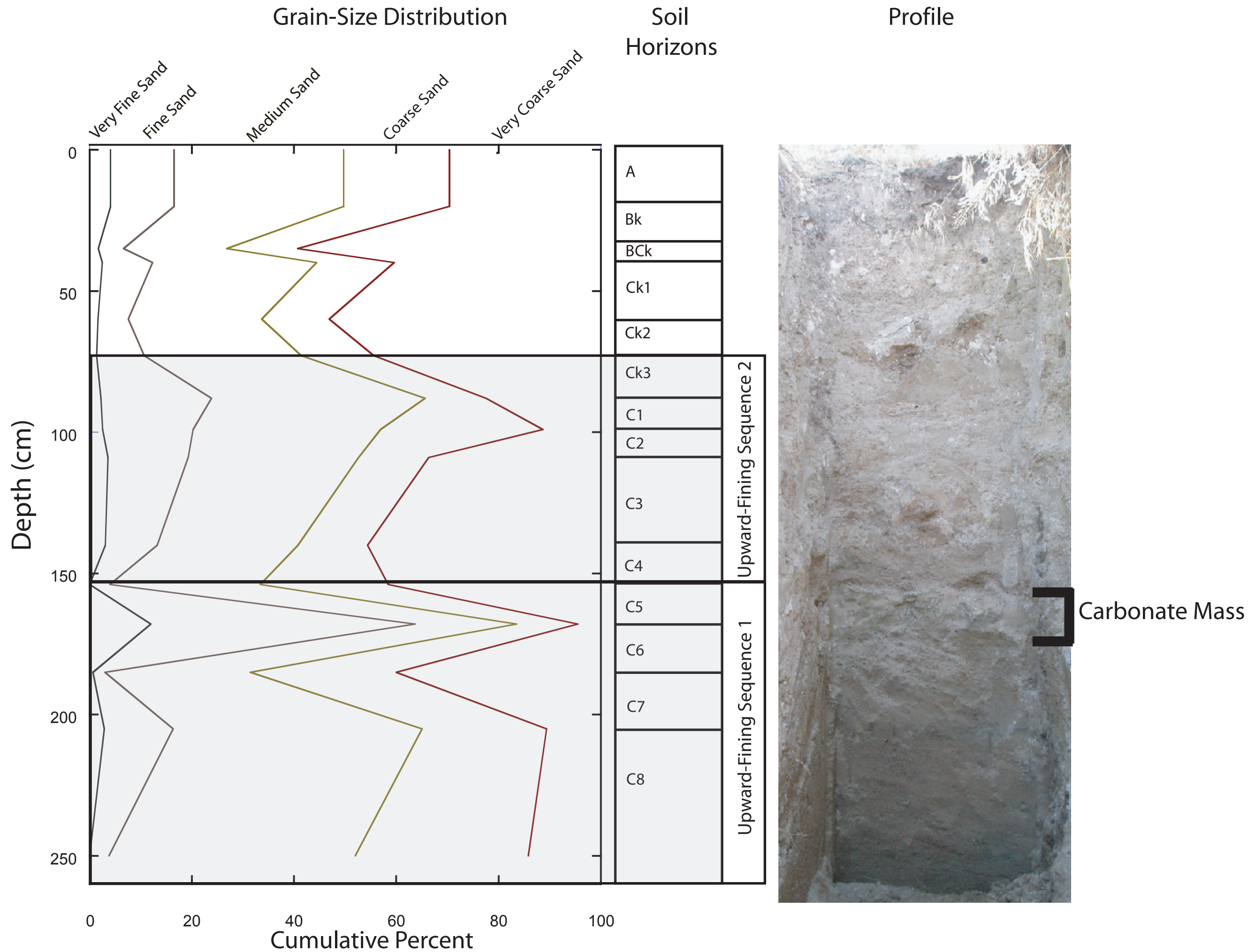



Figure 20. Depth function diagram for Profile 4 inTrench 1 (West wall).

Two thin-sections were prepared from the carbonate mass at a depth of 1.5-1.7 m below land surface and analyzed using optical cathodoluminescence (CL) and epiflorescence (EF) microcopy. These methods were used to determine if the carbonate mass was a tufa suitable for Uranium Series dating.

The orange color in the CL image (Figure 21) is manganese-activated ($Mn^{2+}$) cathodoluminescence in calcite. This reduced manganese was stable in solution in phreatic groundwaters, and was cannibalized from pedogenic manganese oxides (Greg Ludvigson, 2008 personal communication). This suggests the carbonate was recrystallized by groundwater after burial. Silicate sands above and below the carbonate mass exhibit a gradational boundary, also suggestive of *in situ* recrystallization.

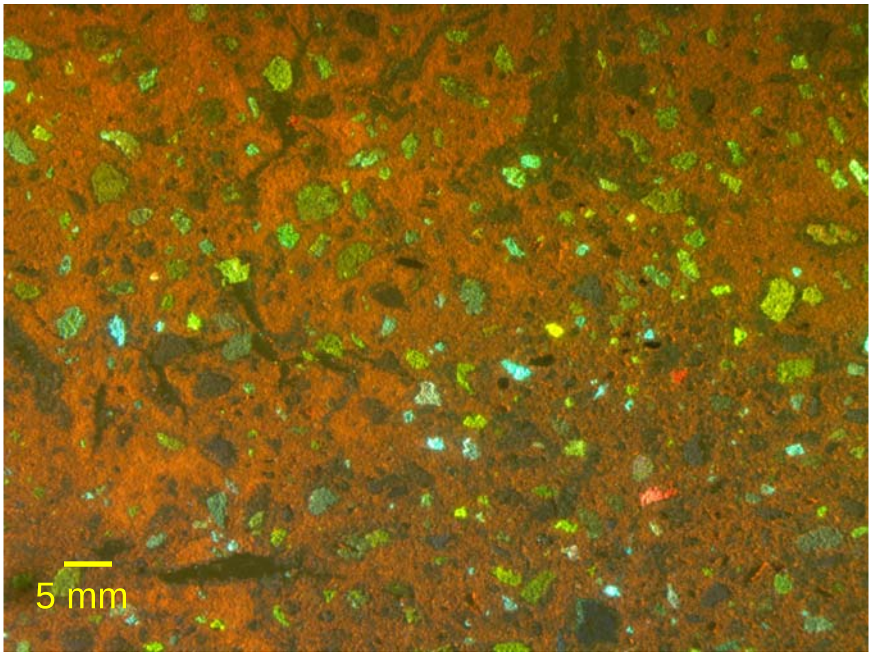
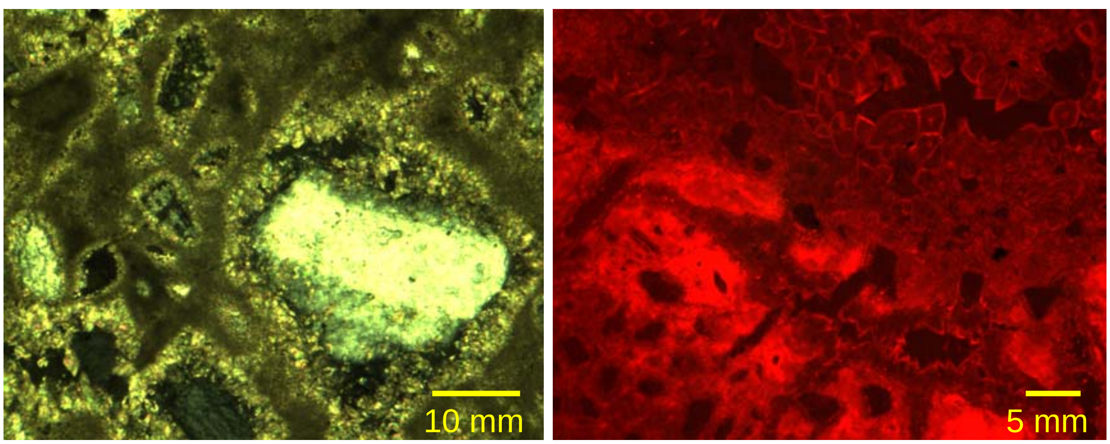



Figure 21. CL image of carbonate mass thin-section.

EF microscopy exhibited significant heterogeneity in emitted light intensity, reflecting contrasts in the purity of the carbonate mass (Figure 22B). Less-intense light suggests an earlier fabric that has been subject to recrystallization. Brightly lit organic acids in pore fluids surround large crystal grains, and many clasts were surrounded by thin rims of calcite. The feldspars in particular, were cannibalized and used to produce the carbonate (Figure 22A) (Luis Gonzalez, 2008 personal communication).




**A.** **B.**

Figure 22. A. Plain-polarized light image of cannibalized grain with calcite rind. B. EF image showing brightly lit organic acids surrounding previously deposited grains. Calcite rinds around crystal grains are also brightly lit.

Trenches 3A and 3B

Two profiles were described at Trenches 3A and 3B (Tables 5 and 6 in Appendix I). In Trench 3B, a large block of rock fall terminated excavations at a depth of 75 cm. Trench 3A was excavated to a depth of 156 cm before reaching rock fall. The profiles in both trenches are similar to a depth of 75 cm. The deposits exposed in the trenches consist of fine, medium, and coarse sands and many angular siliceous pebbles and cobbles of Ogallala material. The poor sorting and angular clasts observed in the trenches are indicative of colluvium.

A modern surface soil and three buried soils, labeled Soil 1-4 from top to bottom, were exposed in Trench 3A (Figure 23). The surface soil (Soil 1) has a weakly expressed A-Bw-C profile. Soil 2, at a depth of 54-93 cm, is represented by a dark grayish brown (10YR 4/2) A horizon (Ab1) with loamy sand texture. Soil 3, represented by the Bwb2 horizon, is at a depth of 93-116 cm, and is dark brown (7.5 YR 3/3) medium sand with common hackberry seeds. The A horizon of Soil 3 was stripped off by erosion, leaving the Bw horizon at the surface before it was buried. Surface exposure and concomitant melanization accounts for the high C content of the Bwb2 horizon (Figure 23). Soil 4, at a depth of 116-156 cm, is represented by the Ab3 horizon, a dark brown (7.5YR 4/2) very fine, fine, and medium sand.

Although no cultural artifacts or features were found in either trench, flecks of charcoal were abundant throughout the Trench 3A profile, and there was an exceedingly high quantity of roots in Soils 3 and 4. Soil organic matter from the upper 10 cm of soils 2, 3, and 4 yielded conventional $^{14}C$ ages of 710 ± 70, 114.9 ±

0.5, and 102.4 ± 0.5 yr B.P., respectively (Table 5). It is possible the age of Soil 2 is a reliable mean residence time, and that Soils 3 and 4 were contaminated by roots and/or charcoal. If the age of Soil 2 is reliable, then it is likely that the rockshelter retreated rapidly over the past 3000 years given the $^{14}C$ ages from Trench 1 in the front of the shelter.

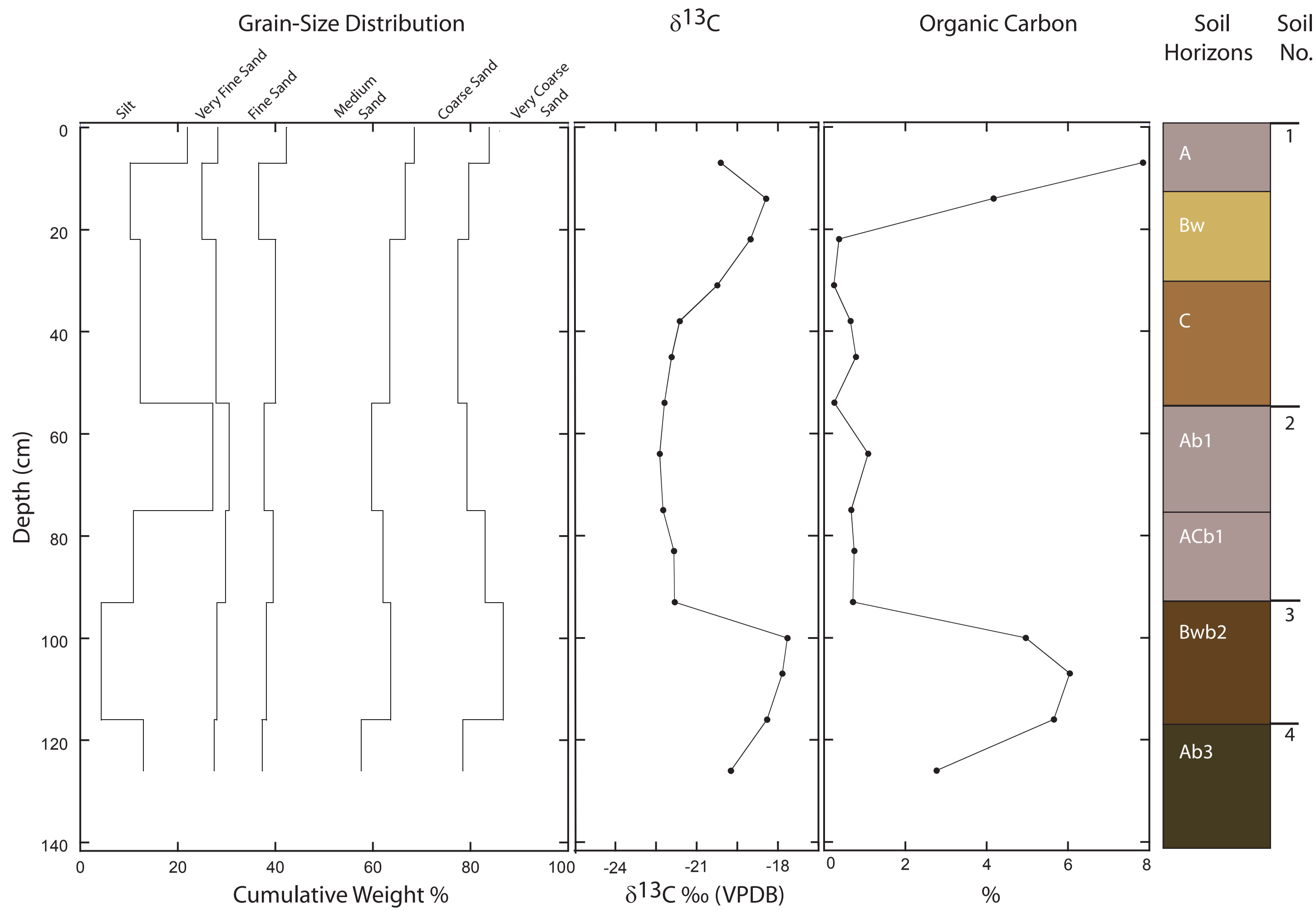



Figure 20. Depth function diagram for Trench 3A.

Table 5. Conventional radiocarbon ages for Trench 3A.

| $^{14}$C yr B.P. | Dating Method | Material | Lab Number |
|---|---|---|---|
| 710±70 | Conventional | SOM[1] | ISGS-6125 |
| 114.9±0.5 | Conventional | SOM | ISGS-6119 |
| 102.4±0.5 | Conventional | SOM | ISGS-6126 |

[1] SOM=Soil organic matter.

Stable carbon isotope data at Trench 3A exhibit heavier $\delta^{13}C$ values than Trench 1 by approximately 3‰, suggesting that the plant community at the back of the shelter is different from the plant community at the front of the shelter. There are three trends in Trench 3A from the bottom of the profile to the top (Figure 23). The $\delta^{13}C$ values in Soils 3 and 4 represent a mixed $C_3$ and $C_4$ plant community. The high C content is these horizons suggests there was a stable surface supporting plant growth. There is an offset of approximately 4‰ toward lighter $\delta^{13}C$ values at the boundary between Soils 2 and 3, and C content decreases up the profile. These rapid changes in $\delta^{13}C$ values and C content are indicative of an erosional surface. The $\delta^{13}C$ values gradually shift back toward a more mixed plant assemblage up the profile.

The phytolith assemblage from Trench 3A corroborates the $\delta^{13}C$ values (Figure 24, Table 2 in Appendix III). At the bottom of the profile, a mixed $C_3$ and $C_4$ grass assemblage is represented Soils 3 and 4. Chloridoids increase and panicoids and pooids decrease in Soil 2. Beginning in Soil 3, woody dicots (i.e. spinulose spheres) and other dicots (i.e. polyhedral and jigsaw shapes) increase up the profile, and trichomes and bulliforms appear in Soil 2, possibly indicating an increase in soil moisture. Also, pooids are well-represented throughout the sequence. Thus, $C_3$

plants were contributing lighter carbon to the soil despite the dominance of $C_4$ grasses.

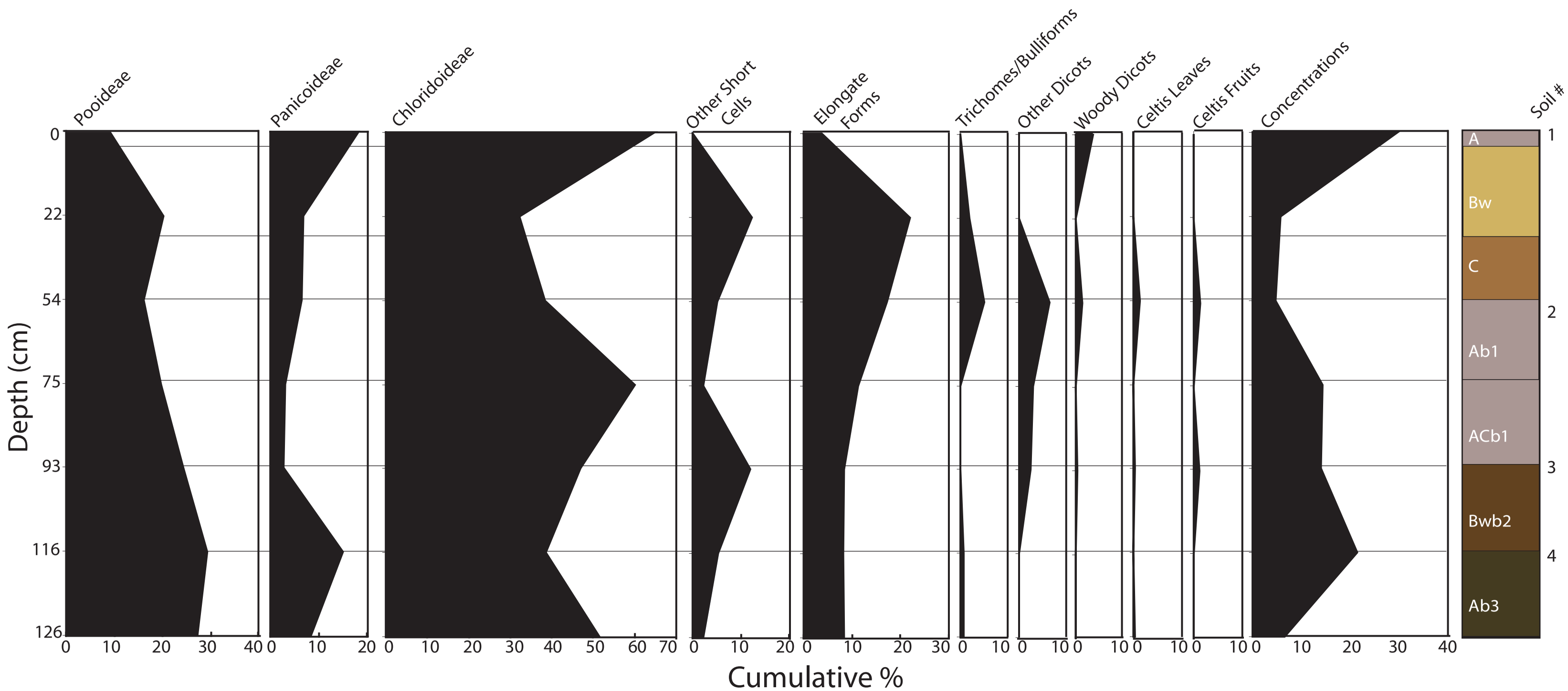



Figure 24. Phytolith diagram for Trench 3A.

# CHAPTER VI

# CONCLUSIONS

The results of investigations at the Burntwood Creek rockshelter indicate that the site was repeatedly occupied during the late Holocene. Stratified cultural deposits comprised of lithic debitage, charcoal, burned earth, and bison elements and fragments of deer- and bison-sized bone, were recorded in the upper 1.8 m of the shelter fill. Radiocarbon ages determined on five charcoal samples range from 2205 ± 20 to 2315 ± 20 $^{14}$C yr B.P. Although the cultural affiliations of the archaeological deposits are unknown, the absence of ceramics, combined with the suite of radiocarbon ages, suggest that Late Plains Archaic people occupied the shelter over a relatively short period. Also, there is a hint of earlier use of the site by Late Paleoindian people. Lithic material exhibiting parallel-oblique flaking, typical of what is produced during Allen point manufacture, was recovered from sediment brought up from the bottom of Trench 1 during trenching. However, the stratigraphic context of this material is uncertain, and the cultural assemblage from the site remains to be studied in detail.

It is likely that groundwater sapping from spring outflow carved the rockshelter in the Ogallala Formation. The resistant Ogallala "caprock" forms the overhang of the shelter. Trench 1 revealed that sediment was delivered to the floor of the shelter through colluvial and alluvial processes during the late Quaternary. Surface flow from spring discharge at the back of the shelter deposited sandy sediment on the floor of the shelter in multiple events. Phreatic groundwater from the Ogallala aquifer, which is the source of the spring, contributed to recrystallization of a carbonate mass in the sandy alluvium. The sandy alluvium was subsequently mantled by colluvium extending east from the drip-line of the shelter. The geometry of the colluvial apron suggests sediment was delivered from the roof and walls of the shelter. There is a shallow draw on the uplands immediately above the shelter. The mouth of the draw is at the edge of the shelter drip-line, creating a pour-off. Water flowing from the pour-off delivers alluvium to the area in front of the shelter fill.

At the distal end of the shelter fill, alluvium from Burntwood Creek mantles colluvium. Grain-size data indicate multiple fining-upward sequences, suggesting that frequent floods occurred along Burntwood Creek, and sediment-laden floodwater reached the front of the shelter.

At the back of the shelter, Trenches 3A and 3B revealed a 1.5-m thick unit of colluvium overlying massive blocks of roof fall or bedrock, and three buried soils are developed in the colluvium. There is an erosional unconformity between Soils 3 and 4. One $^{14}C$ age of 710 ± 70 yr B.P. from Soil 2 may be reliable. Both the unconformity and $^{14}C$ age suggest the back of the shelter may have been exposed to the open air within the last thousand years.

Both CL and EF microcopy of the carbonate mass from Unit I suggest movement of phreatic groundwater through a sandy matrix that was feeding a natural spring at the Burntwood Creek rockshelter. No karophytes, pisoids, radiolarians, or other microfossils were observed in thin-sections of the carbonate mass, dismissing the hypothesis that it is a tufa. Thus, the carbonate mass is not suitable for U-series dating, but the sandy alluvium comprising Unit I may be suitable for optically stimulated luminescence (OSL) dating.

In both Trenches 1 and 3A, the $\delta^{13}C$ values represent $C_3$ or mixed $C_3$ and $C_4$ plant communities. Phytolith analysis yielded a diverse and well-preserved assemblage of $C_3$ and $C_4$ grasses, dominated by grasses of the $C_4$ Chloridoideae subfamily. The abundance of chloridoids throughout both profiles is problematic when comparing $\delta^{13}C$ values with the phytolith data. This suggests that chloridoids may be a better indicator of aridity than stable carbon isotopes. The $C_3$ Pooideae subfamily documented at depth in Trench 1, and throughout the profile in Trench 3A, corroborates lighter $\delta^{13}C$ values. Dicots, such as hackberry (*Celtis occidentalis*), also contributed isotopically lighter carbon in both trenches. The $C_4$ Panicoideae subfamily was not well-represented in both trenches, but an increase was documented at depth in Trench 3A. Differences between floristic composition (Table 1) and phytolith data suggest there is differential phytolith production among the three subfamilies.

Stable carbon isotope and phytolith analyses demonstrate that a complex plant community existed in or around the rockshelter and changed in composition during the late Holocene. This variation could be due in part to input of vegetation from the pour-off at the top of the rockshelter, or may represent changes in water availability from springs. Good phytolith preservation suggests redeposition was limited with the exception of Units I and II in Trench 1. Thus, differences in $\delta^{13}C$ values and phytolith assemblages between Trenches 1 and 3A suggest the rockshelter micro-environment supported a diverse assemblage of plants that would have also been supported by water from Burntwood Creek and springs.

Hackberry leaf and fruit phytoliths as well as burned hackberry seeds were concentrated in Feature 1 in Trench 1. Hackberry leaf phytoliths are more abundant than the fruits. This suggests hackberry trees were growing nearby and may have been used for burning by prehistoric Native Americans. Also, hackberry fruits may have been used as a food source; fruit availability is during summer and fall, and may imply seasonal occupation. It is likely that other $C_3$ trees and shrubs were abundant based on the presence of woody and other dicots, but they were under-represented in the phytolith data compared to the grasses.

## Future Research

Future research at the Burntwood Creek rockshelter will continue under the auspices of the Odyssey Archaeological Research Program. This will include determining a numerical age on the sands comprising Unit I, either through OSL dating or AMS dating of a phytolith isolate. Furthermore, images taken from CL and EF microscopy will be used to make sampling decisions for carbon and oxygen isotopic analyses of the carbonate mass. Also, soil and sediment samples will be collected from the landscape above the shelter for isotope and phytolith data that will be compared to rockshelter data. Finally, a modern soil analog from under a mature hackberry tree will be sampled and analyzed to determine the proportion of leaf to fruit phytoliths.

There are many options to expand this study. First, cultural deposits collected in 2007 need to be intensively analyzed. Hundreds of flakes collected from Trench 1 may offer insight into technology, and faunal analysis may provide new details about subsistence. Also, lateral and horizontal extent of archaeological deposits in the shelter needs to be determined, and deep exploration needs to be conducted to see if there are Late Paleoindian cultural deposits. Although trenching below about 2.5 m is problematic because of groundwater, this task may be accomplished with the assistance of dewatering techniques.

Documentation, dating, and mapping the extent of archaeological deposits, including deeply buried sites, across the Burntwood Creek valley is necessary in order to better understand the history of human occupation in the valley. This should include more intensive investigation at sites 14RW3, 14RW4, and 14RW5. Lastly, there is need for valley-wide geomorphic and paleoenvironmental study to ascertain the age and history of the valley fills, and to reconstruct late-Quaternary paleoenvironments at a regional scale.

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APPENDIX I

Burntwood Creek Rockshelter (14RW418) Soil and Sediment Descriptions

Description of Burntwood Creek Rockshelter (14RW418) Profiles

Table 1. Profile 1, Trench 1 (North Wall)
Date described: July 2, 2007

| Depth (cm) | Unit | Horizon | Description |
|---|---|---|---|
| 0-40 | VII | A | Dark grayish brown (10YR 4/2) pebbly silt, very dark grayish brown (10YR 3/2) moist; weak fine granular structure; friable; many pebbles and cobbles scattered throughout matrix; many fine and very fine roots; many worm casts and open worm burrows; common fine and very fine pores. |
| 40-55 | VI | Bw | Light olive brown (2.5Y 5/3) silt, olive brown (2.5Y 4/3) moist; few fine faint yellow brown (10YR 5/6) mottles, common dark grayish brown (10YR 5/6) organic coatings on ped faces; weak fine subangular blocky structure; friable; laminated in lower 5cm, parts along bedding planes; very few fine pebbles; common fine and very fine roots; many worm casts and open worm burrows; common fine and very fine pores; abrupt wavy upper boundary. |
| 55-73 | V | C1 | Light yellowish brown (2.5Y 6/3) cobbly silt, light olive brown (2.5Y 5/3) moist; fine faint olive yellow (2.5Y 6/6) mottles; massive; firm; many angular pebbles and cobbles (Ogallala); common very fine roots; many worm casts and open worm burrows; common flecks of very fine charcoal; cultural deposits in upper 5cm (flakes, bone, charcoal); abrupt wavy upper boundary. |
| 73-98 | IV | C2 | Reddish brown (2.5YR 5/3) silt, reddish brown (2.5YR 4/3) moist; few fine prominent dark brown (7.5YR 3/3) and common fine distinct olive yellow (2.5Y 6/6) mottles, interbedded with few siliceous pebbles and few angular cobbles (Ogallala); frequency of pebbles decreases to the east; common very fine pores, abrupt wavy upper boundary. |
| 98-110 | III | C3 | Light olive brown (2.5Y 5/3) sand, olive brown (2.5Y 4/3) moist; few fine faint strong brown (7.5YR 5/6) mottles; massive; firm; many angular cobbles and boulders (Ogallala); few very fine roots, few worm casts, common fine and very fine pores; abrupt wavy upper boundary. |

| | | | |
|---|---|---|---|
| 110-190 | II | C4 | Brown 70% (7.5YR 5/4) moist (rubified), dark brown 30% (7.5YR 4/3) fine loamy sand; few fine reddish brown (5YR 4/4) mottles; massive; friable; few pebble-size of strongly weathered clasts of Ogallala; few fine roots; few medium coarse pores; abrupt wavy upper boundary. |
| 190-220 | I | C5 | Olive brown (2.5Y 4/3) moist loamy sand, few fine faint light olive brown (2.5Y 5/4) mottles; massive parting to single grain; loose; few pebble and cobble-size clasts of strongly weathered Ogallala; few fine and very fine roots; abrupt wavy upper boundary. |

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Table 2. Profile 2, Trench 1 (North Wall)
Date described: July 2, 2007

| Depth (cm) | Unit | Description |
|---|---|---|
| 0-40 | VII | Same as above |
| 40-48 | VI | Same as above |
| 48-64 | V | Same as above |
| 64-84 | IV | Same as above |
| 84-99 | III | Same as above |
| 99-166 | II | Same as above |
| 166-186 | I | Same as above |

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Table 3. Trench 1, Profile 3, North Wall.
Date Described: July 19, 2007

| Depth (cm) | Horizon | Description |
|---|---|---|
| 0-150 | C1 | Stratified brown and grayish brown silt loam interbedded with very fine sandy loam; fine-grained silt loam horizontally bedded with insets of colluvium. 0-30cm disturbed by trenching activity; 0-60cm common pebbles and few cobbles scattered through fine-grained matrix; 60-150cm few 5-10 cm thick beds of colluvium. |
| 150-165 | C2 | Poorly sorted colluvium, common cobble and pebble-sized fragments of the Ogallala Formation. These fragments thicken to the west and slope up to the west. Charcoal sample within upper one cm of colluvial layer. |
| 165-215 | C3 | Stratified; brown and grayish brown silt loam |

Table 4. Profile 4, Trench 1, West Wall
Date Described: July 3, 2007

| Depth (cm) | Unit | Horizon | Description |
|---|---|---|---|
| 0-20 | VII | A | Grayish brown (10YR 5/2) pebbly silt loam, dark grayish brown (10YR 4/2) moist, common krotovina 3-5cm in diameter filled with (10YR 4/2) silt loam (10YR 3/2) moist; weak fine subangular blocky parting to weak fine granular structure; friable; many pebbles and common cobbles (Ogallala); many fine and very fine and common medium and few coarse roots; many worm casts and open worm burrows; clear smooth boundary. |
| 20-35 | VI | Bk | Pale brown (10YR 6/3) very coarse, coarse and medium sand, brown (10YR 5/3) moist; weak fine subangular blocky structure; friable; common siliceous pebbles; few rotten cobbles of Ogallala; many fine and medium films and common very fine threads of calcium carbonate; common fine and very fine roots and few medium and coarse roots; common worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary. |
| 35-40 | VI | BCk | Brown (10YR 5/3) moist, very coarse, coarse and medium sand; very weak subangular blocky structure; many siliceous pebbles; many fine and medium films and common very fine threads of calcium carbonate; common fine and very fine roots; common fine and very fine pores; gradual smooth boundary. |
| 40-60 | I | Ck1 | Light yellowish brown (10YR 6/4) very coarse, coarse and medium sand, yellowish brown (10YR 5/4) moist, common fine distinct olive (5Y 5/4) mottles; massive parting to single grain; stratified; few angular pebbles and cobbles (Ogallala); common very fine threads of calcium carbonate; abrupt wavy boundary. |
| 60-73 | I | Ck2 | Light yellowish brown (2.5Y 6/4) very coarse, coarse, and medium sand, olive (5Y 5/4) and olive yellow (2.5Y 6/6 and 6/8) mottles; massive parting to single grain; common large angular cobbles and boulders (Ogallala); few very fine threads of calcium carbonate; common fine very fine and few medium and coarse roots; abrupt wavy boundary. |

| | | | |
|---|---|---|---|
| 73-88 | I | Ck3 | Light yellowish brown (10YR 6/4) very coarse, coarse, and medium sand, yellowish brown (10YR 5/4) moist; massive parting to single grain; few lenses of siliceous pebbles and granules; few fine and medium threads of calcium carbonate; few fine and very fine roots; common open worm burrows; common fine and very fine pores; abrupt smooth boundary. |
| 88-99 | I | C1 | Light yellowish brown (10YR 6/4) fine and medium sand, yellowish brown (10YR 5/4) moist, common fine olive (5Y 5/4) mottles; massive parting to single grain; stratified; interbedded with fine siliceous pebbles; few fine and very fine roots; common fine and very fine pores; abrupt smooth boundary. |
| 99-109 | I | C2 | Brownish yellow (10YR 6/6) medium sand, yellowish brown (10YR 5/6) moist; massive parting to single grain; few lenses of fine siliceous pebbles; few fine and very fine roots; common very fine and few fine pores; abrupt smooth boundary. |
| 109-140 | I | C3 | Light yellowish brown (10YR 6/4) very coarse to coarse sand, yellowish brown (10YR 5/4) moist, common fine faint yellowish brown (10YR 5/6) and olive yellow (5Y 6/6) mottles; massive parting to single grain; stratified; interbedded with fine siliceous pebbles, few cobbles and small boulders (different Ogallala); few fine and very fine roots; common very fine and few fine pores; abrupt wavy boundary. |
| 140-154 | I | C4 | Light olive brown (2.5Y 5/4) very coarse to coarse sand, light olive brown (2.5Y 5/3) moist; massive parting to single grain; stratified; few very fine roots; few fine and very fine pores; abrupt wavy boundary. |
| 154-168 | I | C5 | Light yellowish brown (2.5Y 6/3) moist fine sand; massive; firm; clast supported; many angular cobbles (Carbonate 70% by volume); few very fine roots; abrupt irregular boundary. |
| 168-185 | I | C6 | Light olive brown (2.5Y 5/4) moist fine sand, common fine distinct olive yellow (2.5Y 6/6) mottles; massive parting to single grain; stratified; cross-bedded; interbedded with fine, medium, coarse sand, and very fine siliceous pebbles; few fine and very fine roots; abrupt smooth boundary. |

| | | | |
|---|---|---|---|
| 185-205 | I | C7 | Pale olive (5Y 6/3) medium sand, olive (5Y 5/3) moist; massive; firm; few fine and medium pores, abrupt smooth boundary. |
| 205-250 | I | C8 | Yellowish brown (10YR 5/4) moist coarse to medium sand, common fine faint light olive brown (2.5Y 5/4) and light yellowish brown (2.5Y 6/4) mottles; massive parting to single grain; stratified; few fine and medium pores. |

Table 5. Trench 3A
Date Described: July 2, 2007

| Depth (cm) | Horizon | Description |
|---|---|---|
| 0-14 | A | Grayish brown (10YR 5/2) loamy sand, dark grayish brown (10YR 4/2) moist; weak fine subangular blocky to weak fine granular structure; many angular pebbles and cobbles; friable; many fine and very fine roots; many worm casts and open worm burrows; clear wavy boundary. |
| 14-31 | Bw | Light yellowish brown (2.5Y 6/3) very fine, fine, and medium sand, light olive brown (2.5 5/3) moist; weak fine subangular blocky structure; many angular pebbles and cobbles; friable; common krotovina 6-8cm in diameter filled with A horizon material; many worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary. |
| 31-54 | C | Brown (10YR 5/3) very fine, fine, and medium sand, dark brown (10YR 4/3) moist; massive parting to single grain; friable; many angular pebbles and cobbles; common worm casts and open worm burrows; common fine and very fine pores; abrupt smooth boundary. |
| 54-75 | Ab1 | Grayish brown (10YR 5/2) loamy sand, dark grayish brown (10YR 4/2) moist; weak fine granular structure; common angular pebbles and cobbles; many worm casts and open worm burrows; common very fine and few medium roots; common fine and very fine pores; gradual smooth boundary. |
| 75-93 | ACb1 | Grayish brown (10YR 5/2) very fine, fine, and medium sand, dark grayish brown (10YR 4/2) moist; very weak fine granular structure; very friable; many angular pebbles; many worm casts and open worm burrows; common very fine, few medium, and few coarse roots; common fine and very fine pores; abrupt wavy boundary. |

| | | |
|---|---|---|
| 93-116 | Bwb2 | Dark brown (7.5YR 4/3) medium, dark brown (7.5YR 3/3) moist; weak medium and coarse prismatic to weak fine subangular blocky structure; friable; common fine angular pebbles and few angular cobbles; common fine and very fine roots; common fine and very fine pores; common hackberry seeds; abrupt smooth boundary. |
| 116-156 | Ab3 | Dark brown (7.5 YR 4/2) very fine, fine, and medium sand; weak fine granular structure; very friable; common granules and fine pebbles; few fine and very fine roots. |

Table 6. Trench 3B
Date Described: July 2, 2007

| Depth (cm) | Horizon | Description |
|---|---|---|
| 0-17 | A | Same as above |
| 17-32 | Bw | Same as above |
| 32-54 | C | Same as above |
| 54-75 | Ab1 | Same as above |

APPENDIX II

Recorded Prehistoric Rockshelter/Cave Sites in Kansas

Compiled from Kansas State Historical Society Database

| Site Number | Site Name | KS County | Period | Cultural Affiliation |
|---|---|---|---|---|
| 14BU00386 | | Butler | Middle Ceramic, Late Ceramic, Historic 1854 1900 | Wichita, Osage, Euro-American |
| 14CS00425 | 200 | Chase | Prehistoric American Indian | Unknown |
| 14CT00303 | Ernie's rockshelter site | Chautauqua | Archaic, Early Ceramic, Middle Ceramic, Late Ceramic | Pomona Variant Neosho Focus |
| 14CT00330 | Keplinger site | Chautauqua | Middle Ceramic | Unknown |
| 14CM00304 | Double e-s cave site | Comanche | Archaic, Early Ceramic | Unknown |
| 14DN00624 | Sterling Rocks | Dickinson | Prehistoric American Indian | Unknown |
| 14GL00458 | No map | Greeley | Prehistoric | Unknown |
| 14LC00302 | Ringneck site | Lincoln | Early Ceramic, Middle Ceramic | Unknown |
| 14LC00408 | 89 Palmers Cave/Cave Hollow | Lincoln | Middle Ceramic, Late Ceramic | Possibly Upper Republican or Smoky Hill |
| 14LO00303 | | Logan | Middle Ceramic | Unknown |
| 14LO00401 | Coal-oil Canyon | Logan | Early Ceramic, Middle Ceramic, Late Ceramic | Keith Variant Upper Republican Phase Dismal River Aspect |
| 14LV01044 | | Leavenworth | Prehistoric | Unknown |
| 14LY00477 | 218 | Lyon | Middle Ceramic | Unknown |
| 14MN00470 | | Marion | Prehistoric American Indian | Unknown |
| 14MN00472 | | Marion | Prehistoric American Indian | Unknown |
| 14MT00401 | | Morton | Prehistoric American Indian | Indeterminate |
| 14MY00361 | | Montgomery | Early Ceramic | Kansas City Hopewell |
| 14MY00364 | | Montgomery | Middle Ceramic | Unknown |
| 14MY00378 | | Montgomery | Prehistoric | Unknown |
| 14MY00380 | | Montgomery | Prehistoric | Unknown |
| 14MY01310 | | Montgomery | Early Ceramic | Unknown |
| 14MY01352 | | Montgomery | Early Ceramic | Unknown |
| 14MY01353 | | Montgomery | Prehistoric | Unknown |
| 14MY01356 | | Montgomery | Prehistoric | Unknown |
| 14MY01361 | | Montgomery | Prehistoric | Unknown |
| 14MY01379 | | Montgomery | Prehistoric | Unknown |
| 14MY02301 | | Montgomery | Prehistoric | Unknown |
| 14RU00514 | | Russell | Middle Ceramic | Unknown |
| 14TO00411 | | Trego | Prehistoric | Unknown |
| 14WO00204 | | Woodson | Prehistoric | Unknown |
| 14WO00222 | | Woodson | Early Ceramic, Middle Ceramic | Upper Republican Phase |
| 14WO00227 | | Woodson | Middle Ceramic | Upper Republican Phase |
| 14WO00401 | Dry creek cave | Woodson | Archaic, Early Ceramic, Middle Ceramic | Upper Republican Phase |
| * 14RW00418 | Jack's Rockshelter | Rawlins | Prehistoric | Unknown |

* This study

# APPENDIX III

Opal Phytolith Raw Counts, Calculated Percentages, and Concentrations

Table 1. Phytolith results for Profile 1 in Trench 1.

| Locality | **Burntwood Creek Rockshelter Profile 1, Trench 1: Opal Phytolith Analysis** | | | | | | |
|---|---|---|---|---|---|---|---|
| Unit/Horizon | VII, A | VI, Bw | V, C1 | IV, C2 | III, C3 | II, C4 | I, C5 |
| Depth (cm) | **30-40** | **48-55** | **55-65** | **93-98** | **100-110** | **160-170** | **210-220** |
| Sample weight (g) | 5.42 | 5.58 | 5.35 | 5.18 | 5.25 | 5.33 | 5.6 |
| Lab Number | 07.11.10.1 | 07.11.10.2 | 07.11.10.3 | 07.11.10.4 | 07.11.10.5 | 07.11.10.6 | 07.11.10.8 |
| **PHYTOLITH PERCENTS** | | | | | | | |
| **Pooid** | 8.5 | 14 | 5.3 | 5.3 | 17.9 | 41.8 | 30.6 |
| **Panicoid** | 12.1 | 5 | 1.2 | 4.9 | 5.5 | 7.5 | 7.3 |
| **Chloridoid** | 56.8 | 51.6 | 38.7 | 79.8 | 54.5 | 17.2 | 21.4 |
| **Other short cells** | 4.5 | 1.3 | 2.9 | | 11.1 | 9.6 | 20.9 |
| **Total short cells** | **81.9** | **71.9** | **48.1** | **90** | **89** | **76.1** | **80.2** |
| **Elongated forms** | 12.1 | 9.4 | 14.4 | 6.5 | 9.4 | 16.7 | 18.4 |
| **Trichomes** | | | 2.9 | | | | |
| **Total grass phytoliths** | **94** | **81.3** | **65.4** | **96.5** | **98.4** | **92.8** | **98.6** |
| Celtis leaf | 2 | 6.3 | 23.2 | 2.1 | 1.3 | 0.8 | |
| Celtis fruit | | 1.8 | 7.6 | 0.4 | | | |
| Woody dicots | | 3.1 | | | | 4.2 | |
| Other Dicots (Tracheids, Polyhedral, Jigsaw) | 4 | 7.6 | 4.6 | | 0.4 | 2.1 | |
| **Total dicot types** | **6** | **18.9** | **35.4** | **2.5** | **1.7** | **7.1** | **1.4** |
| ***Burnt grass phytoliths*** | *1.5* | | *0.9* | | | | |
| **PHYTOLITH RAW COUNTS** | | | | | | | |
| **Pooid** | 17 | 31 | 13 | 13 | 42 | 100 | 63 |
| **Panicoid** | 24 | 11 | 3 | 12 | 13 | 18 | 15 |
| **Chloridoid** | 113 | 115 | 94 | 197 | 128 | 41 | 44 |
| **Other short** | 9 | 3 | 7 | | 26 | 23 | 43 |
| **Elongated forms** | 24 | 21 | 35 | 16 | 22 | 40 | 38 |
| **Pointy Forms** | | | 1 | | | | |
| **Total dicots** | 12 | 42 | 84 | 9 | 4 | 17 | 3 |
| **Total phytolith counts** | **199** | **223** | **237** | **247** | **235** | **239** | **206** |
| **Burnt grass phytoliths** | 3 | | 3 | | | | |
| **Charcoal** | | 7 | | 14 | 3 | | |
| **Lycopodium Spores/transect x # transects** | 3 | 9 | 8.25 | 11 | 12 | 14.5 | 10 |
| **Concentration/gram of soil** | 454,910 | 165,051 | 204,640 | 161,126 | 138,650 | 114,946 | 136,733 |

Table 1. Phytolith results for Profile 1 continued.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **RAW COUNTS PER TYPE** | | | | | | | |
| **Short cells** | | | | | | | |
| **Choridoideae** | | | | | | | |
| Short saddles Type 1 | 45 | 66 | 23 | 70 | 57 | 23 | 13 |
| Short saddles Type 2 | 12 | | | 5 | | | |
| Large saddles | 33 | 25 | 46 | 81 | 50 | 6 | 19 |
| Spools | 1 | 2 | 4 | 3 | | | |
| "Squat" saddles | 8 | 22 | 21 | 31 | 21 | 4 | 5 |
| Long saddles | 14 | | | 7 | | 8 | 7 |
| **Panicoideae** | | | | | | | |
| Panicoid bilobates | 9 | 1 | 1 | 7 | 5 | 9 | 8 |
| Polylobates | | | | | | 1 | 2 |
| Crosses Other | 7 | 6 | 1 | 1 | 2 | 5 | 5 |
| Crosses Type 1 | 4 | 4 | 1 | 4 | 6 | | |
| Crosses Type 2 | 4 | | | | | 3 | |
| **Pooideae** | | | | | | | |
| Small, non-sinuous trapezoid | 5 | | 6 | | 16 | 74 | 31 |
| Long wavy trapezoid | | 3 | | | | 9 | |
| Short-sinuous trapezoid | | | | | | 10 | |
| Long straight trapezoidal | | 8 | 5 | | 19 | | 7 |
| Ridged trapezoids | 12 | 20 | 2 | 13 | 7 | 7 | 22 |
| Trapezoid other | | | | | | | 3 |
| Scutiform hooks | | | | | | | |
| Other short cells | | | | | | | |
| Other non-diagnostic | 9 | 3 | 7 | | 26 | 23 | 43 |
| **Long cells** | 24 | 21 | 35 | 16 | 22 | 40 | 38 |
| **Other grass phytoliths** | | | | | | | |
| Trichomes | | | 7 | | | | |
| **DICOTS** | | | | | | | |
| Other | 7 | | 2 | | | 5 | 3 |
| Spinulose spheres (woody dicot) | | 7 | | 3 | | 10 | |
| Celtis type (leaf) | 4 | 14 | 55 | 5 | 3 | 2 | |
| Celtis type (fruit) | | 4 | 18 | 1 | | | |
| Base Hairs | 1 | 6 | | | | | |
| Polyhedral | | 7 | 9 | | | | |
| Jigsaw pieces | | 2 | | | | | |
| Branching Tracheids | | 2 | | | 1 | | |

Table 2. Phytolith results for Profile 5 in Trench 1 and for Trench 3A

| Locality | Trench 1, Profile 5 | | Trench 3A | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Horizon | Alluvium | Alluvium | A | Bw | C | Ab1 | ACb1 | Bwb2 | Ab3 |
| Depth (cm) | 40-50 | 185-195 | 0-7 | 14-22 | 45-54 | 64-75 | 83-93 | 107-116 | 116-126 |
| Sample weight (g) | 5.26 | 5.42 | 4.97 | 5.18 | 4.99 | 5 | 5.09 | 5.01 | 5.22 |
| Lab Number | 07.5.11.3 | 07.11.10.7 | 07.5.11.1 | 07.5.11.2 | 07.5.11.4 | 07.5.11.5 | 07.5.11.6 | 07.5.11.7 | 07.5.11.8 |
| PHYTOLITH PERCENTS | | | | | | | | | |
| Pooid | 21.6 | 19.3 | 9.6 | 21 | 16.8 | 20.5 | 25.3 | 30.3 | 28.2 |
| Panicoid | 3.7 | 2.1 | 18.3 | 6.8 | 6.5 | 3 | 2.8 | 15 | 8.4 |
| Chloridoid | 53.7 | 25.1 | 64.8 | 32.2 | 38.3 | 60 | 47 | 38.6 | 51.6 |
| Other short cells | 2.6 | 6.4 | | 12.2 | 5.1 | 2.2 | 12 | 5.2 | 2.2 |
| Total short cells | 81.6 | 52.9 | 92.7 | 72.2 | 66.7 | 85.7 | 87.1 | 89.1 | 90.4 |
| Elongated forms | 14.9 | 32.6 | 3.7 | 22 | 17.3 | 11.2 | 8.4 | 8.2 | 8.4 |
| Other grass phytoliths | 0.7 | 0.5 | | 2 | 5.1 | | | 0.7 | 0.7 |
| Total grass phytoliths | 97.2 | 86 | 96.4 | 96.2 | 89.1 | 96.9 | 95.5 | 98 | 99.5 |
| Celtis leaf | 1.5 | | | | 1.4 | | 0.4 | | 0.4 |
| Celtis fruit | 0.7 | | | | 1.4 | | 1.2 | | |
| Woody dicots | | 0.5 | 3.7 | | 1.4 | | 0.4 | | |
| Other Dicots (Tracheids, Polyhedral, Jigsaw) | 0.4 | 13.4 | | | 6.5 | 3 | 2.4 | | |
| Total dicot types | 2.6 | 13.9 | 3.7 | 3.9 | 10.7 | 3 | 4.4 | 1.9 | 0.4 |
| Burnt grass phytoliths | 3 | 1.6 | | 10.2 | 12.6 | 16.8 | 17.7 | 1 | 1.1 |
| PHYTOLITH RAW COUNTS | | | | | | | | | |
| Pooid | 58 | 36 | 21 | 43 | 36 | 55 | 63 | 81 | 77 |
| Panicoid | 10 | 4 | 40 | 14 | 14 | 8 | 7 | 40 | 23 |
| Chloridoid | 144 | 47 | 142 | 66 | 82 | 161 | 117 | 103 | 141 |
| Other short | 7 | 12 | | 25 | 11 | 6 | 30 | 14 | 6 |
| Elongated forms | 40 | 61 | 8 | 45 | 37 | 30 | 21 | 22 | 23 |
| Other grass phytoliths | 2 | 1 | | 4 | 11 | | | 2 | 2 |
| Spicule | 1 | | | | | | | | |
| Total dicots | 6 | 26 | 8 | 8 | 23 | 8 | 11 | 5 | 1 |
| Total phytolith counts | 268 | 187 | 219 | 205 | 214 | 268 | 249 | 267 | 273 |
| Burnt grass phytoliths | 8 | 3 | | 21 | 27 | 45 | 44 | 3 | 3 |
| Charcoal | 18 | 16 | 1 | 27 | 30 | 26 | 32 | 17 | 23 |
| Lycopodium Spores/transect x # transects | 3.75 | 14 | 1.5 | 7 | 9 | 4 | 3.5 | 2.5 | 8 |
| Concentration/gram of soil | 505,022 | 91,602 | 1,091,915 | 210,145 | 177,118 | 498,078 | 519,525 | 792,366 | 242,994 |

Table 2 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RAW COUNTS PER TYPE** | | | | | | | | | |
| **Short cells** | | | | | | | | | |
| **Chloridoideae** | | | | | | | | | |
| Short saddles Type 1 | 57 | 12 | 75 | 12 | 8 | 80 | 42 | 32 | 60 |
| Short saddles Type 2 | | | 9 | 12 | 13 | | | | |
| Large saddles | 72 | 30 | 47 | 27 | 37 | 41 | 44 | 62 | 75 |
| Spool | 4 | | | | 1 | 5 | 1 | 2 | 1 |
| "Squat" saddles | 11 | 5 | 11 | 7 | 11 | 22 | 18 | 7 | 5 |
| Long saddles | | | | 8 | 12 | 13 | 12 | | |
| Panicoideae | | | | | | | | | |
| Panicoid bilobates | 3 | 2 | 23 | 11 | 7 | 2 | 1 | 15 | 10 |
| Polylobates | | | | | | | | | |
| Crosses Other | 1 | 2 | 7 | | | | | 4 | 10 |
| Crosses Type 1 | 2 | | | 1 | 3 | 6 | 3 | 12 | 1 |
| Crosses Type 2 | 4 | | 10 | 2 | 4 | | 3 | 9 | 2 |
| Pooideae | | | | | | | | | |
| Small, non-sinuous trapezoid | 32 | 17 | | 16 | 9 | 19 | 28 | 24 | 45 |
| Long wavy trapezoid | 6 | 9 | 4 | 5 | 6 | 8 | 4 | 2 | |
| Short-sinuous trapezoid | | | | 4 | 4 | 5 | 2 | | |
| Long straight trapezoidal | | 1 | | 1 | 3 | 2 | 5 | 2 | 2 |
| Ridged trapezoids | 15 | 2 | 12 | 5 | 6 | 6 | 1 | 11 | 9 |
| Square trapezoids | 1 | 6 | | 6 | 3 | 4 | 5 | 5 | 1 |
| Large rounded trapezoid | 2 | | | 2 | 4 | 6 | 11 | 29 | 20 |
| Trapezoid other | 1 | | 5 | 1 | 1 | | 5 | 8 | |
| Scutiform hooks | 1 | 1 | | 3 | | 5 | 2 | | 2 |
| **Other short cells** | | | | | | | | | |
| Other non-diagnostic | 7 | 12 | | 25 | 11 | 6 | 30 | 14 | 6 |

Table 2 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Long cells** | 40 | 61 | 8 | 45 | 37 | 30 | 21 | 22 | 23 |
| **Other grass phytoliths** | | | | | | | | 2 | |
| Trichomes | | 1 | | 4 | 6 | | | | |
| Bulliforms | 2 | | | | 5 | | | | |
| **DICOTS** | | | | | | | | | |
| Other | | 7 | | 3 | 1 | 3 | 1 | 2 | |
| Spinulose spheres (woody dicot) | 2 | 1 | 8 | | 3 | | 1 | 3 | |
| Celtis type (leaf) | 4 | | | | 3 | | 1 | | |
| Celtis type (fruit) | | | | | 3 | | 3 | | 1 |
| Base Hairs | | 5 | | | 6 | 2 | 2 | | |
| Polyhedral | | 12 | | 3 | 5 | 1 | 2 | | |
| Jigsaw pieces | | | | | 2 | 1 | | | |
| Brancing Tracheids | | 1 | | 2 | | 1 | 1 | | |
| **Other** | | | | | | | | | |
| Spicule | 1 | | | | | | | | |

APPENDIX IV

Procedure for Extracting Phytoliths from Soil (Bozarth 2006)

## Procedure for Extracting Phytoliths from Soil

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11/15/06

### Sample Preparation

Dry loose sediment in paper bag or desiccator.

Check #'s on beakers, centrifuge bottles and tubes.

1. For loose sediment, shake sample through a 2 mm (2000µm) sieve or thoroughly mix in plastic bag. If sample is in block form (such as clayey fields at Blue Creek), then take sub-sample vertically. It is most efficient to process eight samples at one time.

2. Place 10 gram of sediment[1] in a 400 ml beaker for most contexts in sites in karst topography (20 g may be too much, see 03.10.30.5-7). Use 5 gram samples for the Great Plains and American Southwest unless sandy.

### Removal of carbonates

3. Add 25 ml 10% hydrochloric acid (HCL) (2 parts distilled water to 1 part HCL). If reaction occurs, wait 5-10 minutes and add more HCL. Repeat until there is no reaction. If strong reaction occurred, then it may necessary to wash off side of beaker with jet of $H_20$.

4. Transfer sample to a 250 ml centrifuge bottle.

5. Add distilled water to make the bottle 3/4 full, balance, shake, and centrifuge in an IEC floor-model centrifuge at setting 25 for 5 minutes. Decant slowly or siphon if sample is sandy. If plant material or foam adheres to inside of bottle, twist bottle while decanting to wash it out. Watch to determine if sediment starts to run out, if so, centrifuge again and siphon off supernatant. Repeat once. This will wash out the HCL.

### Removal of colloidal organics, clays, and very fine silts

6. Add 100 ml sodium pyrophosphate solution (71.4 g sodium pyrophosphate in 1600 ml distilled water). Shake sample and wash off inside of bottle with fine jet of distilled $H_20$ if necessary. Place sample in ultrasonic bath for 15 minutes. (Check to

determine if sample is being "mixed"; corners seem to work best. It may be necessary to move samples around in bath). Let set overnight if clayey!

7. Add distilled water to make the bottle 3/4 full, balance, shake, and centrifuge at setting 17 for 5 minutes. Pour supernatant through 8 μm nitex filter using an aspirator. This allows clays and fine silts to pass through but prevents discarding most phytoliths (may be too coarse for some spinulose spheres). Stop decanting if nitex stops up. Squirt nitex with jet of distilled water. Wash filter off over beaker. Repeat this step at slower speeds (e.g., 15, 13, 12...) for five minutes as long as most of supernatant can be decanted and until supernatant is relatively clean. May need to repeat step 6 after decanting 2-3 times if sample is very clayey. Transfer contents of beaker back into centrifuge bottle after next to last centrifugation. After last decantation, add water, shake, and pour through 125 μm sieve if plant material or coarse sand is present. Transfer to bottle.

Step 7 is necessary as fine sediment must be removed or clumps will form in the isolate. This step should be done the same day or clays may flocculate as in 03.10.30.5-7

8. Add distilled water to make bottle ½ full, balance, shake, and centrifuge at setting 25 for 5 minutes. Siphon off most of supernatant (down to "ring" above base of bottle) , being careful not to draw up any sediment. Repeat steps 6 and 7 if clay aggregates persist.

9. Transfer sample to 40 ml glass centrifuge tube (shake bottle and pour into beaker; add ca. 10 ml $H_20$ to bottle, shake and pour into beaker; swirl beaker and pour into tube) balance, and centrifuge at setting 25 for 5 minutes. Decant or siphon out supernatant.

**Oxidation for American Southwest or Great Plains**

10. Add 10 ml $H_20_2$, stir with vortex mixer, add 20 ml (up to $2^{nd}$ level on tube rack), and place in hot water bath at setting 4 overnight to remove organics. Note: oxidation of Arizona sediment samples with Schulze solution[2] in a hot water bath at setting of 7 apparently causes certain minerals such as mica to become artificially "light".

**Oxidation for karst topography**

10. Add 5 ml $H_20_2$ Caution, strong reaction may occur If strong reaction occurs (typical of samples from Nakbe', reservoir at La Milpa, and Chunchucmil), it may be necessary to transfer sample back into beaker to avoid "foaming over". Repeat after 15 minutes until ca. 25 ml of $H_20_2$ have been added (up to $2^{nd}$ level on tube rack).

Place tube in warm water bath overnight at setting 4 in fume hood to remove organics.

11. Add distilled water to dilute $H_20_2$ and reduce sediment in suspension, balance and centrifuge at setting 25 for 5 minutes. Siphon or decant supernatant into drain with water running.

12. Add ca. 10 ml distilled water, stir with vortex mixer, add another 20 ml distilled water, balance, and centrifuge at setting 25 for 5 minutes and decant. Repeat.

13. Wash into 50 ml round-bottom centrifuge tube, add additional water if needed, balance, and centrifuge at setting 25 for 5 minutes and decant (pipette if sample is sandy or small).

**Introduction of spike spores**

14. Add 1-6 *Lycopodium* spike spore tablets (1 for BC fields) and 20 ml 10% HCL (up to 1$^{st}$ level on tube rack). Wait ten minutes for tablets to dissolve, then add 20 ml distilled water (up to 2$^{nd}$ level), balance, shake (use rubber stoppers), centrifuge at setting 25 for 5 minutes, and decant. Blot top of centrifuge tube after decantation. Don't rinse so that supernatant can be decanted completely.

**Heavy liquid flotation and centrifugation**

15. Add 20 ml $ZnBr_2$ (sp. gr. 2.40) to sample, stir on vortex mixer using rubber stopper in tube, and centrifuge at setting 25 for one hour[3]. Decant into a 100 ml round bottom centrifuge tube.

If phytolith concentration very low, then add 10 ml $ZnBr_2$ (sp. gr. 2.3) to sample, stir and centrifuge as before. Decant into same 100 ml centrifuge tube. This step is usually not necessary

**Dilution of sample**

16. Add 60 ml distilled water to 100 ml centrifuge tube, balance, shake, and centrifuge at setting 25 for 10 minutes. Phytoliths will sediment to bottom of tube. Decant dilute heavy liquid into bottle for recycling. Wash small isolates, e.g., BC fields, through nitex to remove any remaining clay to avoid clumping of final isolate. Note: floating a 2nd time rarely significantly increases the isolate purity. However, if phytolith concentration is low, then it may help to transfer to 12 ml tube and centrifuge @ 5 for 30 minutes in 10 ml $ZnBr_2$ (2.3 sp. gr.) Heat TBA.

**Washing and dehydration of isolate**

17. Add ca. 3 ml distilled water, stir with vortex mixer, and pour into 12 ml centrifuge tube. Repeat as necessary to insure complete transfer of isolate. Balance and centrifuge at moderate speed (4-5) on tabletop centrifuge for 5 minutes, decant, and blot tube with a Kimwipe.

18. Add small amount of hot TBA, stir with vortex mixer, and decant into 1 dram glass vial. Repeat until all of isolate is in vial. Balance and centrifuge at moderate speed for 5 minutes.

**Isolate storage**

19. Remove most of supernatant by suction pipetting. Be careful to keep pipette above phytoliths. Set the vial on a slide warmer (setting 4-5) with the cap ajar to evaporate residual TBA.

[1] 5 grams dry sediment = 7.85 grams wet (decanted after centrifugation). 1.57 g wet = 1 g dry

[2] Schulze solution is made by adding three parts concentrated nitric acid ($HNO_3$) to one part saturated potassium chlorate ($KCLO_3$), which is made by adding 7.1 g dry powdered $KCLO_3$ to 100 ml distilled water.

[3] After decantation, 2.3 bead will float but 2.35 (and 2.4) beads will not, demonstrating that 20ml of $ZnBr_2$ @ sp. gr. 2.4 is correct. When recycling, if $ZnBr_2$ is ca. 2.0, then boil for ca. 13 minutes.